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CONCRETE TIES - MEASUREMENT OF RAIL IMPACT FORCES FROM STATIONARY DROP TESTS AND EVALUATION OF RESILIENT RAIL SEAT PADS

Prepared for

TRANSPORT CANADA
TRANSPORTATION DEVELOPMENT CENTRE

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre (TDC) of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la table des matières.

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17. Abstract

Impact forces generated by wheel and rail defects subject concrete ties to stresses which can exceed the first crack design stress. Whether the currently used rail-tie seat pads on CN concrete tie track are capable of attenuating such impact forces to any significant degree was investigated in laboratory tests.

A laboratory method of measuring impact loads on a three-tie stub track was devised, and the ability of five tie pads to attenuate impact loads was measured.

The laboratory tests indicate that tie pad stiffness has to be substantially reduced before a significant reduction in tie forces can be achieved. The physical constraints of the fastening system currently in use would require searching for a pad material of desirable characteristics and also designing a pad format to satisfy the above requirements.

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17. Résumé

Les chocs résultant de défauts et d'avaries des rails et des roues peuvent susciter dans les traverses en béton des contraintes parfois supérieures à leur résistance théorique à la fissuration. Une recherche a été faite en laboratoire visant à déterminer la valeur de l'amortissement dynamique apporté par les semelles en caoutchouc couramment utilisées dans les voies ferrées du CN.

La méthode mise au point consiste à laisser choir un essieu monté instrumenté sur un tronçon de voie comptant trois traverses et à mesurer l'amortissement dynamique apporté par les semelles. Cette méthode a servi à caractériser cinq types différents de semelles.

Les essais ont montré que la raideur des semelles devra être considérablement réduite si l'on veut obtenir une réduction significative dans les efforts transmis aux traverses. A moins de revoir à fond les systèmes d'attaches utilisés actuellement, il faut trouver un matériau ayant toutes les caractéristiques voulues et réétudier la forme des semelles.

18. Mots-clés	19. Diffusion
Traverses en béton précontraint, chocs, amortissement dynamique, semelles	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

CN Rail's first major installation of concrete ties, 10,000 ties in 1972 on the Mountain Region, employed a soft rubber pad on the tie-rail seat. This type of pad tends to have a short life span and in later installations of concrete ties, to overcome such deficiencies as pad distortion and work hardening, a harder plastic pad was also used.

Determining whether this pad or some other pad would be more suitable requires that some CN Concrete Tie Pad Specification Standards be redefined. In this regard, assessing the ability of the tie pad to attenuate the stresses imposed on the concrete tie by interaction of wheel-rail surface irregularities, and particularly interaction of wheels with tread defects at or exceeding the condemnable limit, is a desirable objective.

The scope of this report covers the development of a laboratory test method for measuring the impact force that is generated at the head of rail and measuring how much of this force is absorbed by the tie pad.

Two tie pad types currently in use on CN concrete tie track, two tie pad types selected from tie pads received for laboratory examination, and one of the above pad types modified to secure possible greater attenuation, were used in the force attenuation measurements.

The test results have shown that it is not possible to obtain any significant attenuation of impact forces with rail-tie pads that are only 5 mm thick.

More statistical data covering magnitude of rail seat moments versus frequency of occurrence on CN concrete tie track should be accumulated to provide the confidence level necessary to specify an optimum tie pad stiffness or pad thickness for CN operating conditions. Laboratory measurements have indicated a pad thickness is required that will not be compatible with the fastener clip now in use.

SOMMAIRE

Lorsque, pour la première fois, le CN a utilisé en forte quantité des traverses en béton (10 000 traverses posées en 1972 dans le secteur des Rocheuses), des semelles en caoutchouc souple avaient été intercalées entre la traverse et le patin du rail. Or, vu la courte durée de vie de ce type de semelles, et afin de remédier à certains défauts tels que déformation et durcissement, des semelles en matériaux plastique plus résistant ont été utilisées par la suite.

Mais, avant de fixer son choix sur tel ou tel type de semelles et apporter les changements nécessaires dans le cahier des charges du CN, il faudra être en mesure de vérifier l'aptitude des différentes semelles à amortir les efforts transmis aux traverses et suscités par les défauts des roues et des rails, notamment lorsqu'il s'agit de roues dont la bande de roulement a attein ou dépassé le seuil de la mise au rebut.

Le présent rapport rend compte de la mise au point d'une méthode d'essai en laboratoire destinée à mesurer les efforts exercés sur le champignon du rail et à caractériser l'amortissement dynamique apporté par la semelle.

Deux types de semelles couramment utilisés sur les traverses en béton du CN, deux autres types choisis parmi les semelles remises au laboratoire pour examen et un type parmi ceux-ci, mais modifié pour apporter un meilleur amortissement dynamique, ont servi à ces essais.

Ceux-ci ont montré qu'aucun amortissement dynamique de quelque importance n'est possible lorsque les semelles n'ont que 5 mm d'épaisseur.

Il faudra obtenir davantage de données sur l'amplitude des moments de flexion du rail sur les voies à traverses en béton du CN, et sur la distribution statistique des valeurs correspondantes, si l'on veut pouvoir se prononcer avec une certitude suffisante sur la raideur et l'épaisseur optimales à donner aux semelles, dans les conditions opératoires propres au CN. De leur côté, les essais de laboratoire ont débouché sur une valeur d'épaisseur non compatible avec le système d'attaches couramment utilisé.

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1. INTRODUCTION

The soft rubber tie pad used in CN concrete tie track is prone to displacement and rapid wear deterioration. A high density ethyl vinyl acetate pad also in use has provided a better performance record but has a static stiffness of approximately five times that of the rubber pad. It is the determination of attenuation of tie impact forces as related to the stiffness or resilience of the tie pad that is of concern here.

Pads similar to the two tie pad types used on CN concrete tie track have also been used in Amtrak's North East corridor concrete tie track. Large numbers of Amtrak's concrete ties, reasonably similar in static strength to CN's concrete ties, have developed rail seat hairline cracks. Analysis of measured dynamic wheel-rail load data indicated that high impact loads generated by severe wheel tread defects at train speeds above 70 mph were responsible for such cracks. It was concluded that a more resilient tie pad was necessary to provide greater attenuation of impact loads.(1)

Although CN concrete tie track is generally located where train speeds are much below 70 mph, the possibility still exists that cars with condemnable wheel defects will either generate the impact loads equivalent to those required to crack the tie under static conditions or, more likely, load the tie into the minimum fatigue cracking moment zone. Field measurements of tie loads to date suggest that tie loads required to develop minimum fatigue cracking moments occur less than 1% of the time. Laboratory fatigue tests indicate that many repetitions of minimum fatigue cracking moments are required to produce the first hairline crack.(2)

Ref. (1) Investigation of the Effects of Tie Pad Stiffness on the Impact Loading of Concrete Ties in the North East Corridor, DOT/FRA/ORD-83/05. April 1983.

Ref. (2) Impact Loading Measurements on CN60A Concrete Ties, Transport Canada Report No. TP 2649, J.F. Scott, November 1980.

To date, field performance of the CN60A concrete tie has been satisfactory. No significant number of rail seat cracks have been detected.

It is evident that we must find pads that will provide greater force attenuation without compromising other service requirements. Pad characteristics should be verified by the laboratory method used for developing the data in this report.

2. CONCLUSIONS

1. The range in stiffness for hard and soft pads as defined by Load/Deflection test requirements of CN concrete tie pad specifications provides very little difference in attenuation of impact loads.

   Selection of a tie pad for impact force attenuation based on such a limited range of pad stiffness values cannot be made logically.

2. The nominal pad thickness of 5 mm in CN pad specifications is too restrictive to provide the necessary volume of pad material required for absorbing and dissipating large impact loads.

3. A nominal pad thickness of 9 mm would be a more realistic value for pads where a significant reduction in impact force is required. This thickness is not compatible with CN current rail fastening system.

4. An impact load of 60 kips produced the following tie maximum bending moments: +320 in.-kips in Rail Seat +ve, -160 in.-kips in Rail Seat -ve, and -90 in.-kips at tie center (-ve moment). These bending moments exceeded the minimum laboratory fatigue moment level for first micro-crack but were below the average laboratory static first crack moment. At the 60 kip wheel/rail impact loading level, all 5 pad types tested allowed sufficient impact forces to pass into the tie to produce rail seat bending moments exceeding the fatigue micro-cracking moment threshold. This provides a strong indication that wheel impact loading on concrete tie territory should not be permitted to exceed 60 kips. With data now being assessed from wheel loading impact detectors, the incidence of "bad" wheels will shortly be documented on the CN system.

3. RECOMMENDATIONS

More statistical data covering magnitude of rail seat moments versus frequency of occurrence on CN concrete tie track should be accumulated to provide the confidence level necessary to specify an optimum tie pad stiffness or pad thickness for CN operating conditions. Laboratory measurements have indicated a pad thickness is required that will not be compatible with the fastener clip now in use.

R rch work should continue.

4. THREE-TIE STUB TRACK AND INSTRUMENTATION

The three-tie stub track shown in Exhibit No. 1 was adopted as the tie pad loading fixture after a series of tests on a rock ballasted test track proved less than satisfactory. Comments on earlier tests are included in Appendix 1.

Wheel impact force, rail force and tie strains were measured on the three-tie stub track. The impact force, F_I, at instant of wheel striking the rail, was measured by a strain gauge bridge located on the wheel plate. The force transmitted by the rail, F_R, to the two outboard ties was measured as shear by a strain gauge bridge located on the web of rail. The difference between F_I and F_R values, F_T, is the force shared by tie pad and central tie under the impact wheel.

With tie pad removed from middle tie, the calibrated outputs were 1380 lb. (the static weight of the impact wheel assembly on one rail) from both the F_I and F_R bridge circuits or zero lb. when impact wheel was raised from rail. A load cell and a load fixture were used to calibrate these circuits.

A quick release jack placed on a platform straddling the middle tie was used for lifting and releasing the wheel assembly at the "B" end of the tie. The weight of the wheel assembly at the "A" end of the tie provides static load to restrain tie reaction to impact load as in real track where two wheels are on rail.

Middle tie reaction to wheel impact was measured by strain gauges applied to the tie at locations shown in Exhibit No. 1.

For signal conditioning and receiving data from all strain gauge circuits, Honeywell Accudata control and D.C. amplifier units were used. Frequency response filters were all set at wide band position to capture full amplitudes of signals at higher frequencies.

For recording and processing data, a 6-channel Kyowa tape recorder and a 2-channel Nicolet storage oscilloscope, coupled to an X-Y plotter, were used. Also a Brush oscillograph was used to display data from tape played back at one-tenth of the recording speed.

5. PRESENTATION OF DATA AND DISCUSSION OF RESULTS

The data presented in this report is arranged to show the force levels, tie reactions and force attenuation obtained with 5 sets of tie pads designated as A, B, C, D and E respectively. Each pad was assigned a specific identifying line in each chart exhibit as follows:

Pad A	——— ———
Pad B	- - - - - -
Pad C	————————
Pad D	.....
Pad E	xxxxxxxxxx

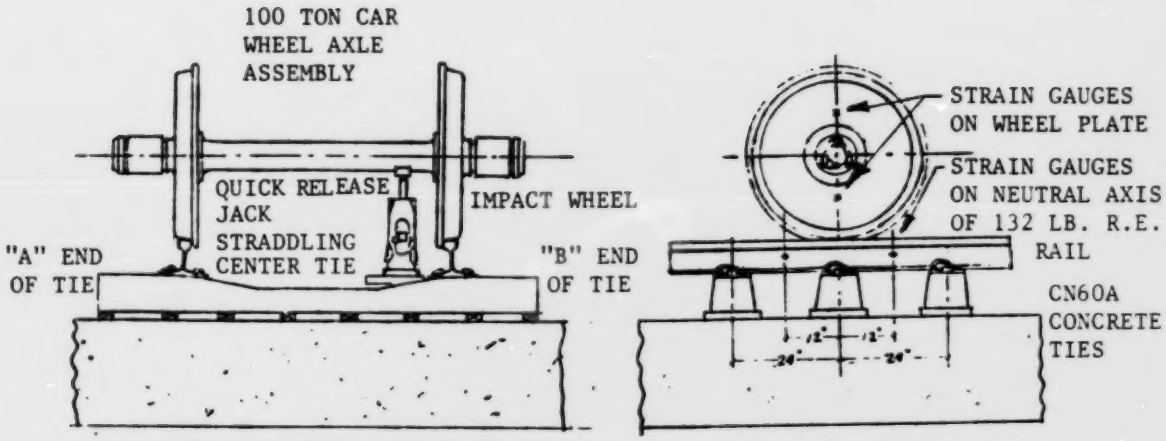
Pad characteristics are shown in Table No. 1.

5.1 Pad Static Stiffness Measurement

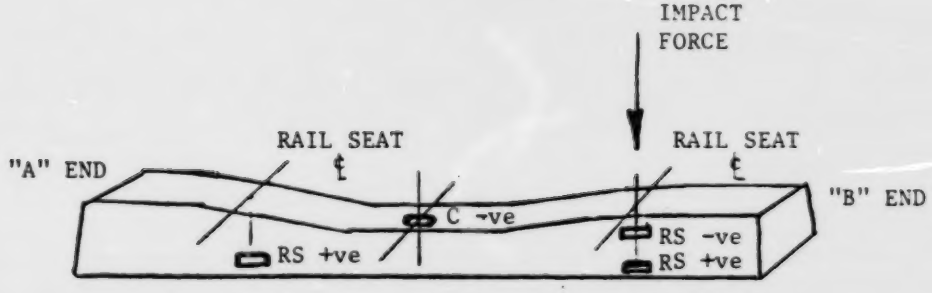
Load-deflection curves for the 5 pads are shown in Exhibit No. 2. Deflections were measured with the whole pad under compression and zero was established at 50 pounds preload.

Pad static stiffness in Table No. 1 was calculated from deflections measured at 4,000 and 20,000 lb. respectively. A straight line relationship between load and deflection is assumed.

Pad E was made up as an experimental pad to obtain a much reduced pad stiffness. The holes were provided for the pad material to deform into under impact loading.



THREE-TIE STUB TRACK



LOCATION OF STRAIN GAUGES
APPLIED TO CENTER TIE

EXHIBIT NO. 1

THREE-TIE STUB TRACK
FOR IMPACT LOADING AND
TIE PAD ATTENUATION MEASUREMENTS

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

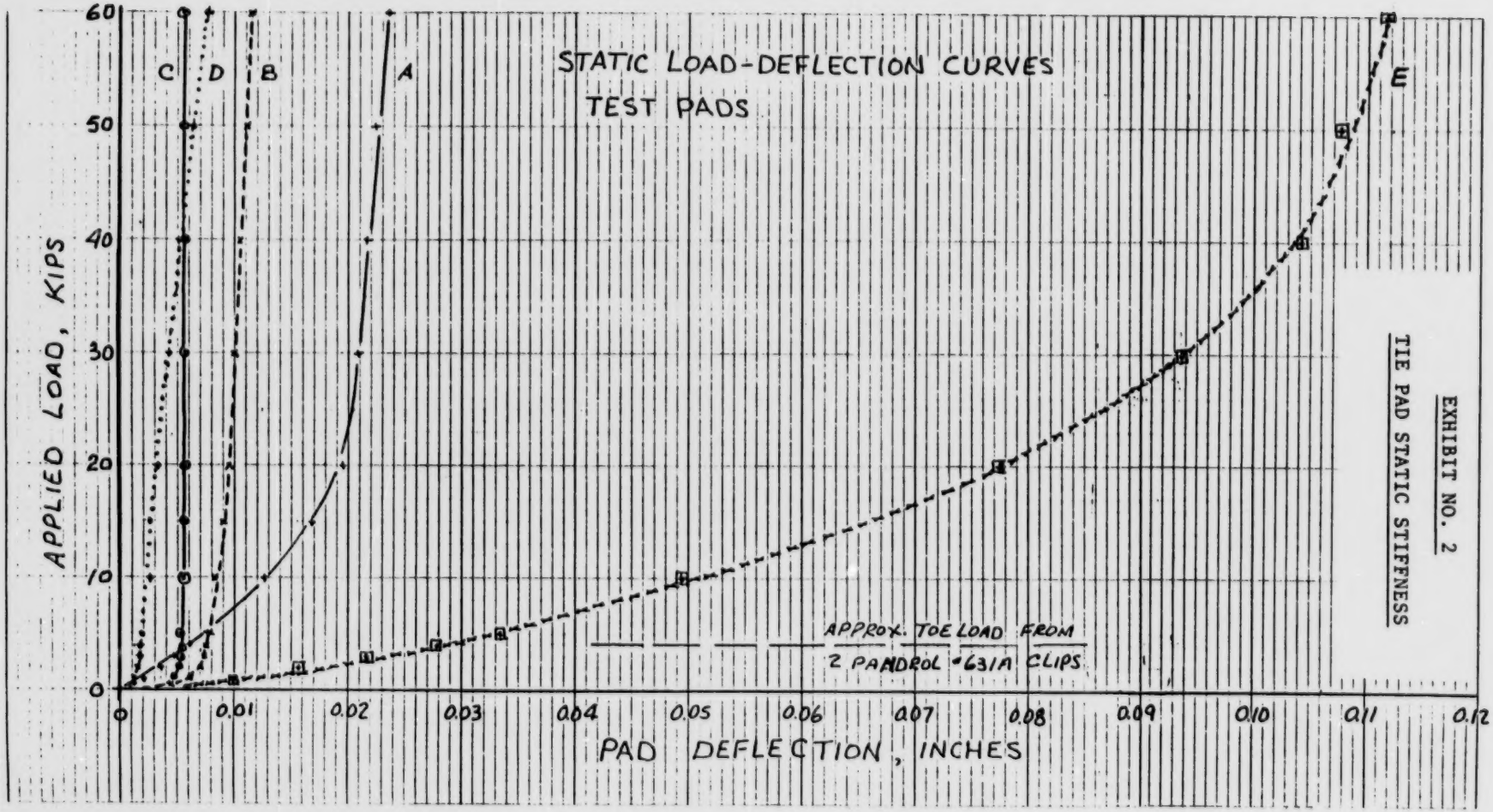


EXHIBIT NO. 2

TIE PAD STATIC STIFFNESS

TABLE NO. 1

CHARACTERISTICS OF TEST PADS

Pad	Pad Characteristic	Pad Material	Pad Configuration	Nominal Pad Thickness mm, inch	Pad Hardness Shore A or D Scale	Pad Static Stiffness lb./in.
A	Relatively soft	Styrene butadiene rubber	Grooved faces	4.57, 0.180	65-70A	1.17×10^6
B	Much harder than rubber pad	Ethyl vinyl acetate	Slab faces	5, 0.194	40-42D	9.412×10^6
C	Very hard	Nylatron GRS	Slab faces	5, 0.194	78-80D	53.33×10^6
D	Intermediate hardness	Poly-sulfide	Slab faces	5, 0.197	45-48D	11.43×10^6
E	Soft	Styrene butadiene rubber	Grooved faces, two single A pads sandwiched together and 20-11/16" dia. holes uniformly spaced punched out of rail seat bearing area.	9, 0.360	65-70A	0.324×10^6

5.2 Sample Records of Data Measurement for Soft and Hard Pads

Typical chart samples of data recorded for a soft and a hard pad at similar drop heights are shown in Exhibits No. 3 and 4 respectively. The rail seat and tie center bending signals have high frequency reverse bending fluctuations superimposed on the initial bending cycle.

For determining the attenuation capability of a pad, the primary peak excursion only of each recorded parameter was read. In the case of rail seat negative, "B" end, primary excursion is in compression, hence tension strain on reversal of stress was read. "A" end rail seat negative tension strains were too low to distinguish from the noise component in the signal and were ignored.

Tie strains were converted to bending moments by multiplying the strain by a "K" factor[3] having the following values:

Rail Seat	+ve	- 0.850 in.-kips per micro in. per in.
Rail Seat	-ve	- 0.823 in.-kips per micro in. per in.
Tie Center	-ve	- 0.285 in.-kips per micro in. per in.

5.3 Impact Forces Generated by Wheel Assembly Drops on Three-Tie Stub Track

The curves of forces F_I, F_R and F_T displayed in Exhibit No. 5, were drawn as straight lines for "the best fit" through data that had several kips of scatter. Off hand, it would appear that at the same drop height of say 3 inches, the impact force with Pad A should have been higher than that with Pad E since Pad E has a static stiffness one-third that of Pad A. Excluding Pad A, a 3 inch drop height, F_I forces increase in the same order as pad stiffness increases. F_I curves falling into a narrower band width for all 5 pads would have been more appropriate.

Ref. (3) Transport Canada Report No. TP 2647, Characteristics of the CN60A Concrete Cross Tie, November 1980, J.F. Scott.

With F_R forces, pad stiffness bears no relationship to rail shear forces generated. If the theory of a softer pad distributing more load to adjacent ties is applicable to a three-tie stub track then, at a 3 inch drop height for example, the stiffest pads should produce the lowest rail shear, instead the reverse had occurred.

Tie force F_T is a derived force from the difference of F_I and F_R and will be subject to error magnification arising from F_I and F_R errors. The variation in results from the expected based on pad stiffness ranking may be due to imprecise curve fitting of data with a large scatter for curves that lie in a narrow band width.

A 1,380 lb. wheel assembly (half weight of wheelset) dropped from a height of 3 inches generated an impact force of approximately 60 kips. Of this force the rail absorbed approximately 35 kips which in turn was transferred to the two outer ties and the balance of about 25 kips was the force absorbed by the middle tie and pad.

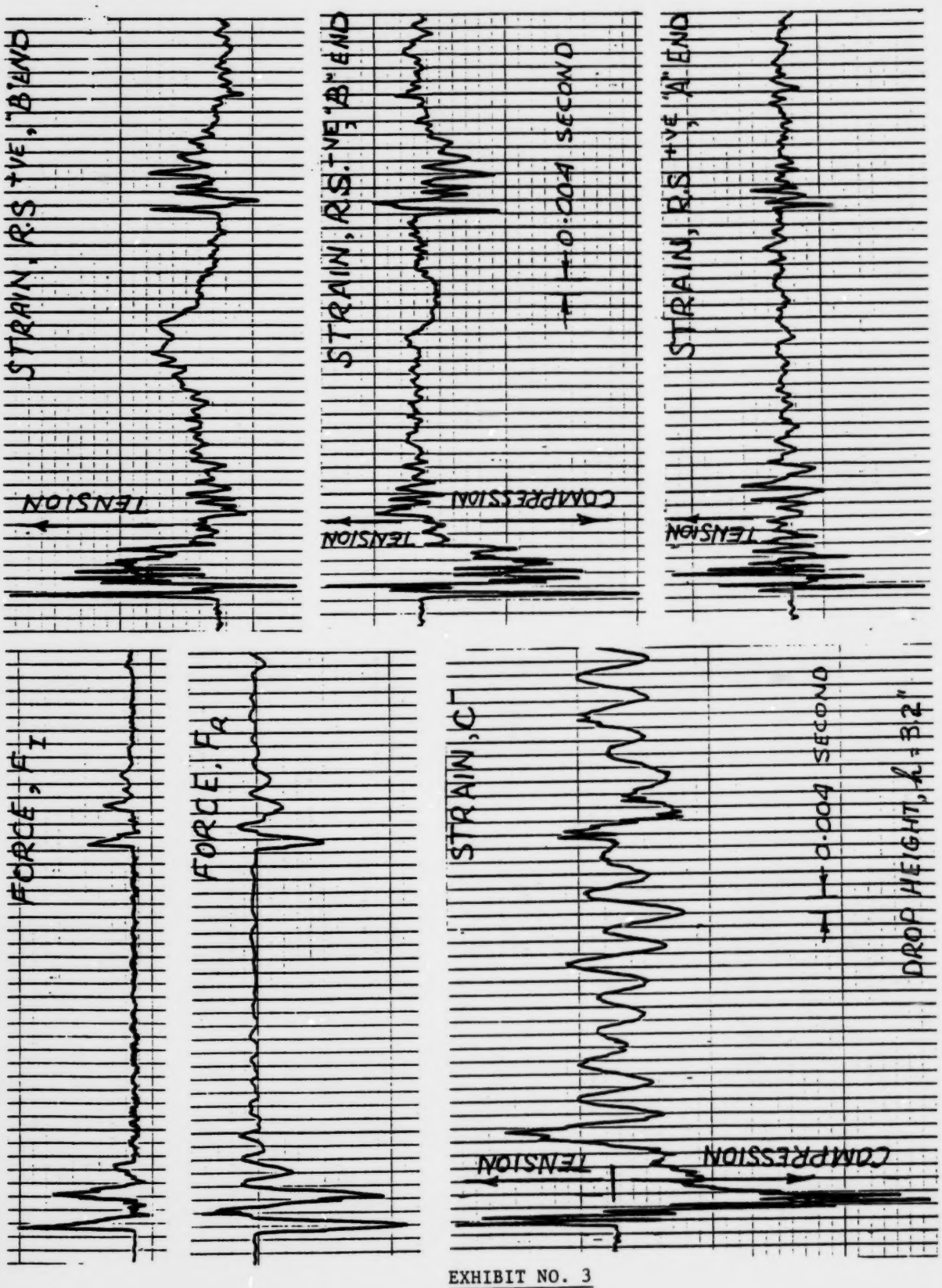


EXHIBIT NO. 3

CHART SAMPLE,
DROP TEST MEASUREMENT, SOFT PAD A

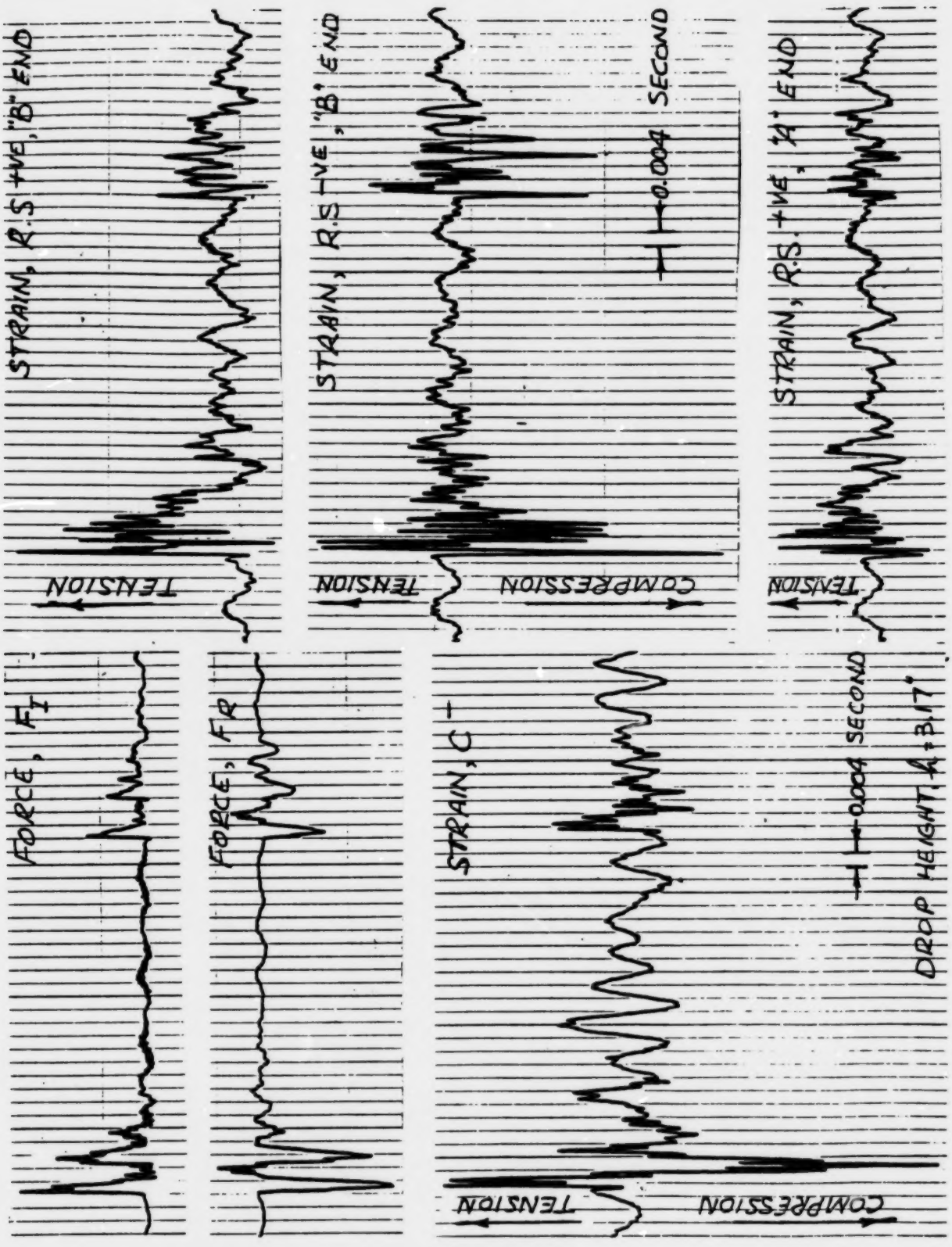


EXHIBIT NO. 4

CHART SAMPLE,
DROP TEST MEASUREMENT, HARD PAD C

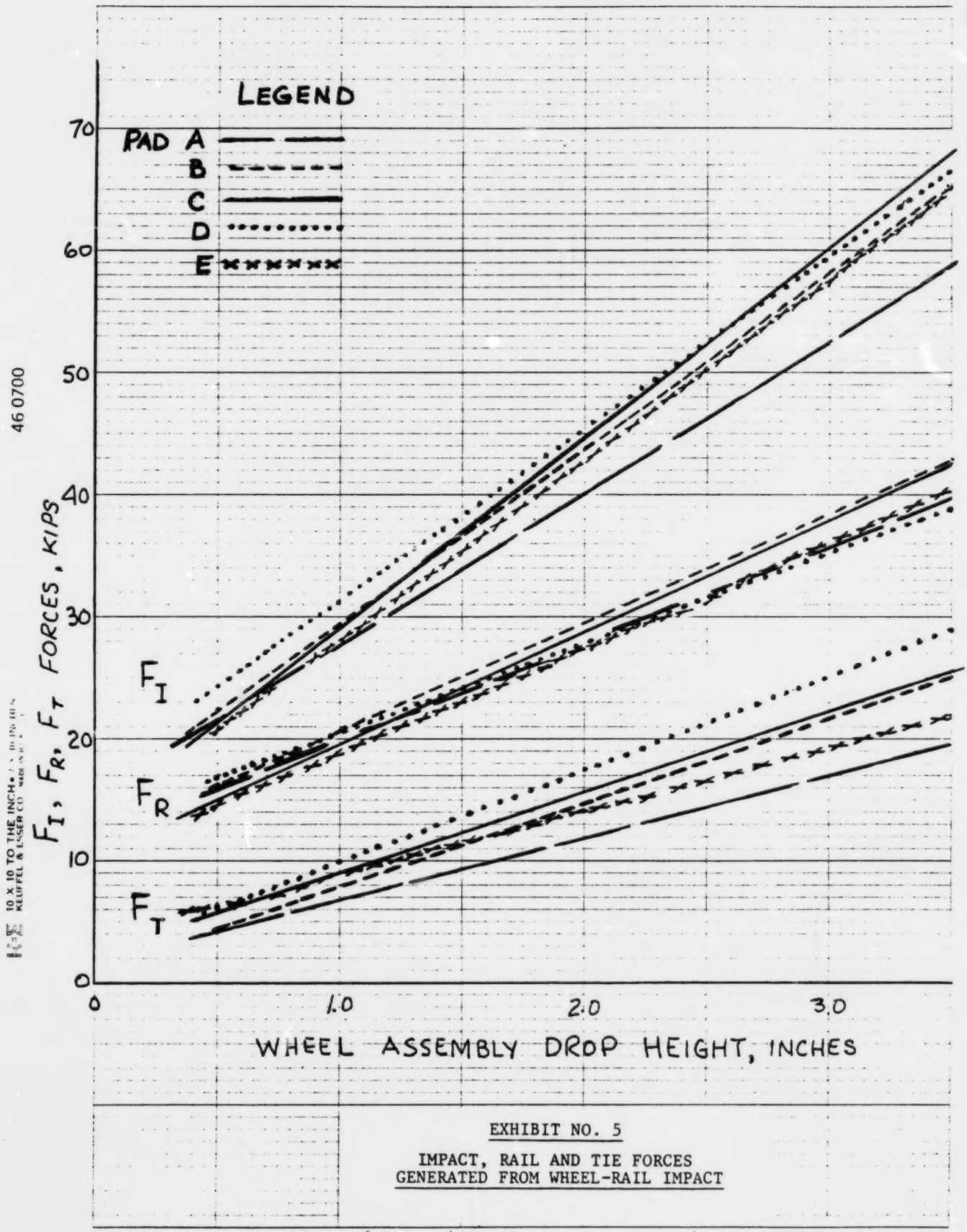


EXHIBIT NO. 5

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL-RAIL IMPACT

5.4 Tie Force vs Wheel Impact Force

Transferring data in Exhibit No. 5 to a plot of tie force vs wheel impact force for Exhibit No. 6, the slope of the curves gives the relationship between tie force and impact force.

F_T is a measure of that portion of the impact force to be transferred through the tie pad to the rail seat of the center tie.

A 60 kip impact force produced approximately a tie force of 19 kips with Pad A, 21.5, 22, 22.5 kips with Pads E, B and C respectively and 25 kips with Pad D. This is more or less in keeping with the order of increasing pad stiffness producing increasing tie forces.

5.5 Rail Seat Bending Moments vs Tie Force

To assess the reaction of the tie to tie force, rail seat bending moments are plotted against tie force in Exhibit No. 7. The softest pad, Pad E, gave the lowest rail seat moments.

Pad A gave the highest rail seat moments. If plotting error is discounted, the high rail seat moments attributed to Pad A may be thought of as the result of the pad stiffness being too low for the thickness of pad.

Pad D with a higher stiffness than Pad B provided the second lowest bending moments for the same pad thickness, suggesting that other material properties as well as stiffness determine the pad's attenuation capability.

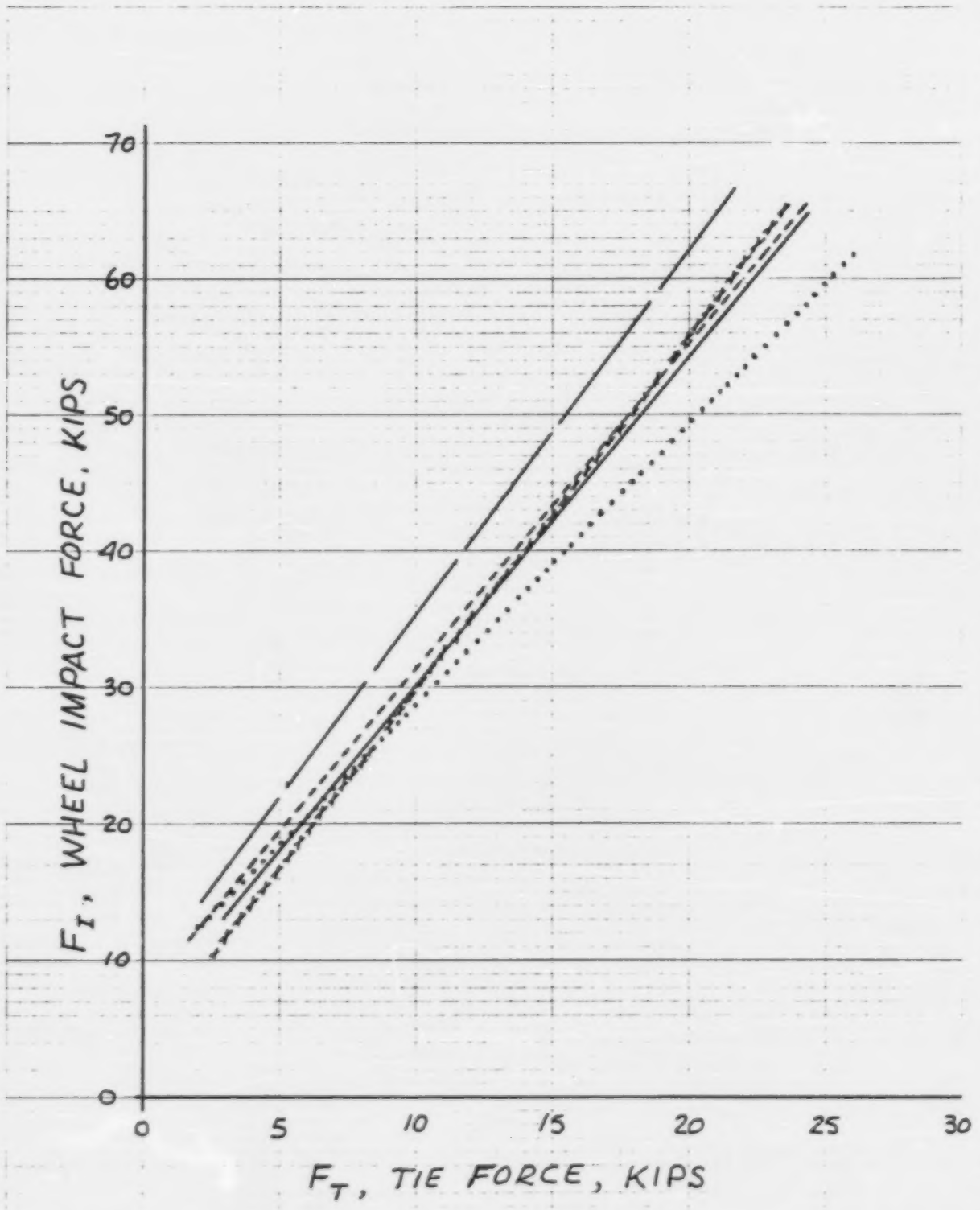
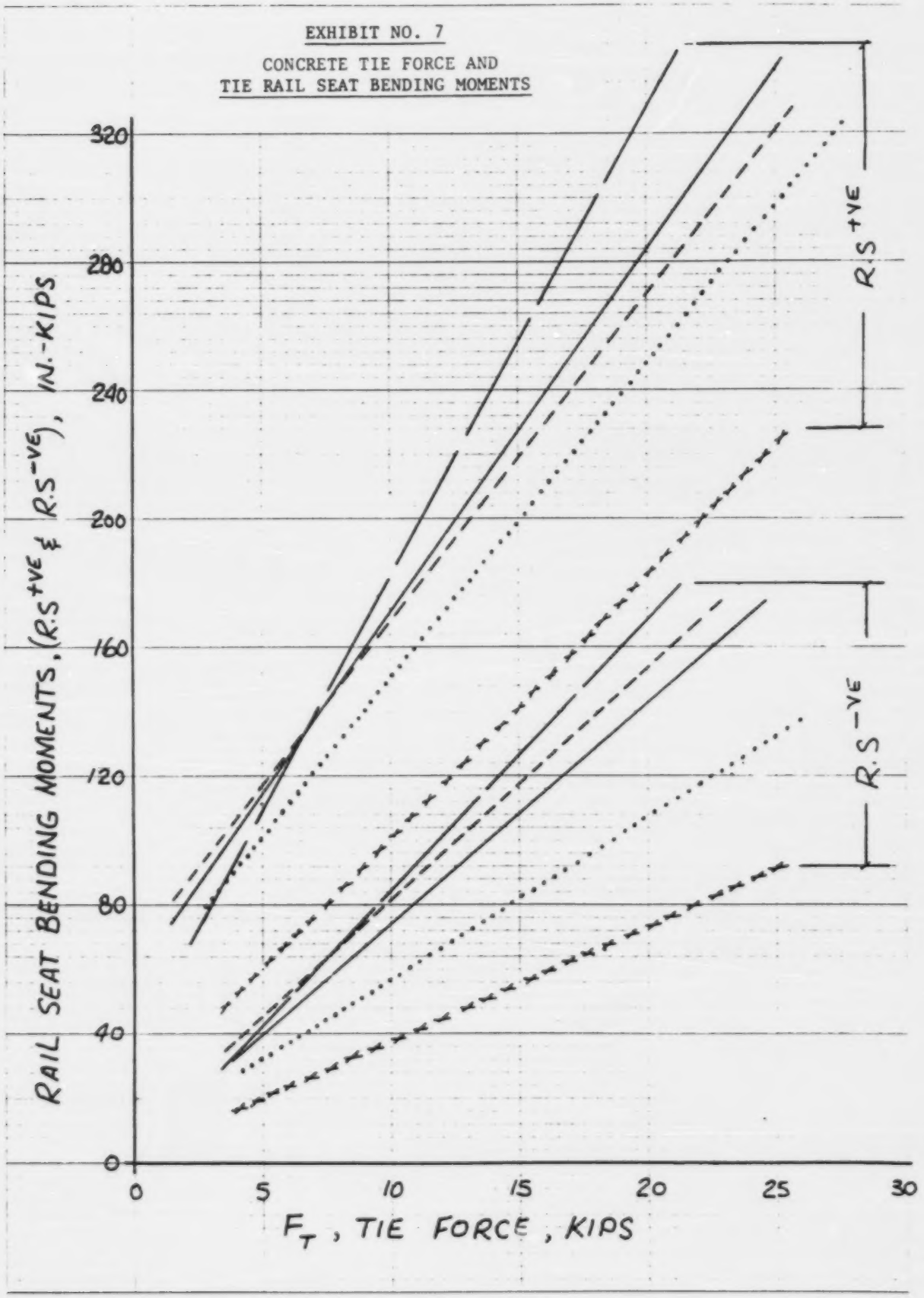


EXHIBIT NO. 6

CONCRETE TIE FORCE AND WHEEL IMPACT FORCE

EXHIBIT NO. 7

CONCRETE TIE FORCE AND
TIE RAIL SEAT BENDING MOMENTS



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5.6 Tie Pad Attenuation from Bending Moment vs Impact Force

In Exhibits No. 8, 9, 10 and 11, tie force, F_T has been replaced by impact force F_I for comparing attenuation of the tie pads. A 60 kip impact force produced approximately the following bending moments:

RS +ve B end, Pad E	200 in.-kips	Pads A,B,C, & D	300 in.-kips
RS -ve B end, Pad E	80 in.-kips	Pads A,B,C	150 in.-kips
		Pad D	130 in.-kips
RS +ve A end, Pad E	60 in.-kips	Pads A,B,C	180 in.-kips
		Pad D	160 in.-kips
C -ve Pad E	60 in.-kips	Pads A,B,C,D.	85 in.-kips

From CN laboratory tests, the following average static moment levels are required for developing the first visible surface crack.

CN60A Tie:

RS +ve + 376, RS -ve - 175, C -ve - 178 in.-kips

CN60B Tie:

RS +ve + 330, RS -ve - 262, C -ve - 235 in.-kips

From the above data, ratios of measured moment at a 60 kip rail impact force, F_I, to first static crack moment shown in Table No. 2 give a view of pad attenuation efficiency and improvement required. It is assumed that the same impact forces generate similar bending moments in the CN60A and CN60B ties.

EXHIBIT NO. 8

WHEEL IMPACT FORCE AND
TIE RAIL SEAT +ve BENDING MOMENT, "B" END

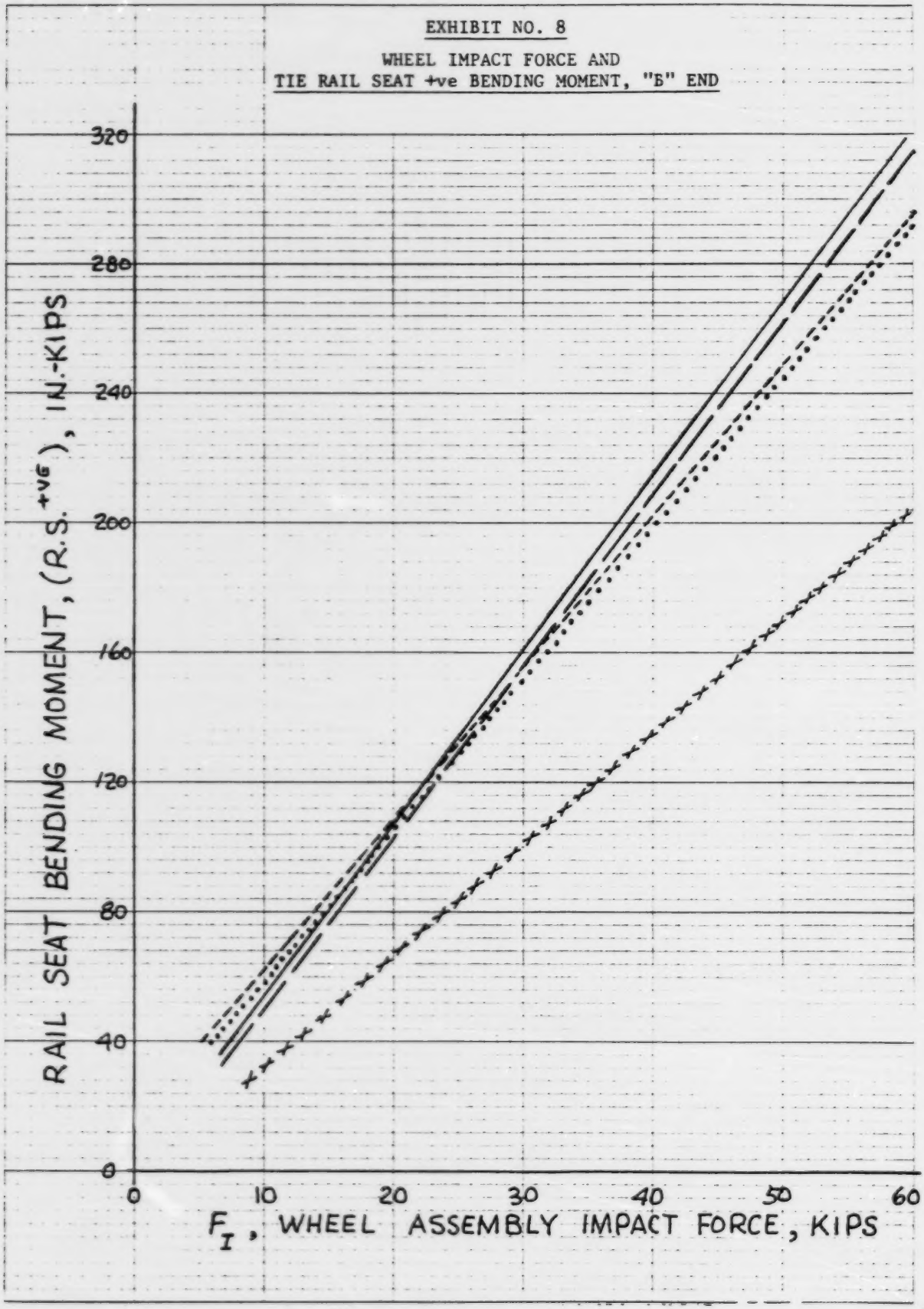

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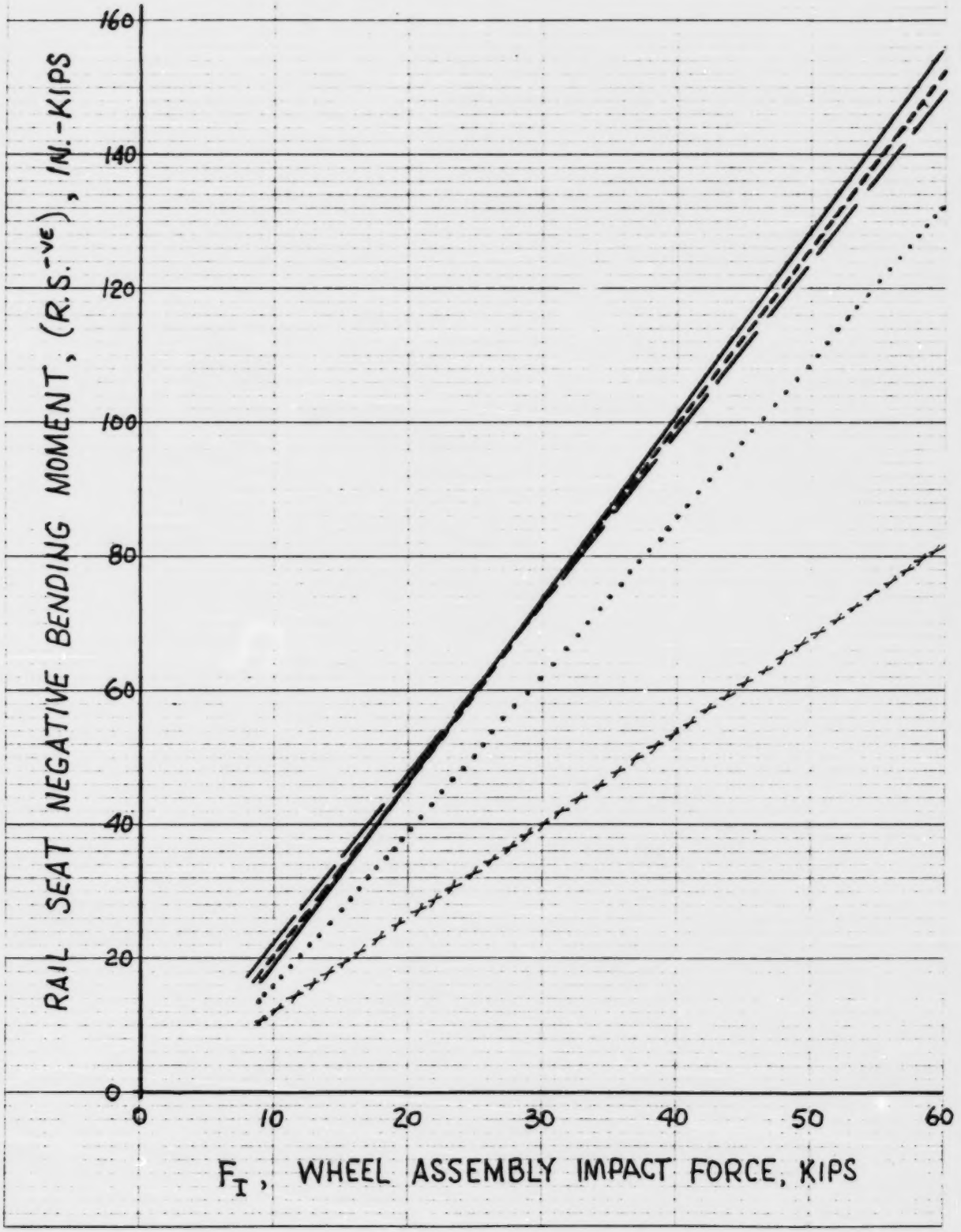
EXHIBIT NO. 9

WHEEL IMPACT FORCE AND
TIE RAIL SEAT -ve BENDING MOMENT, "B" END



46 0700

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EXHIBIT NO. 10

WHEEL IMPACT FORCE AND
TIE RAIL SEAT +ve BENDING MOMENT, "A" END

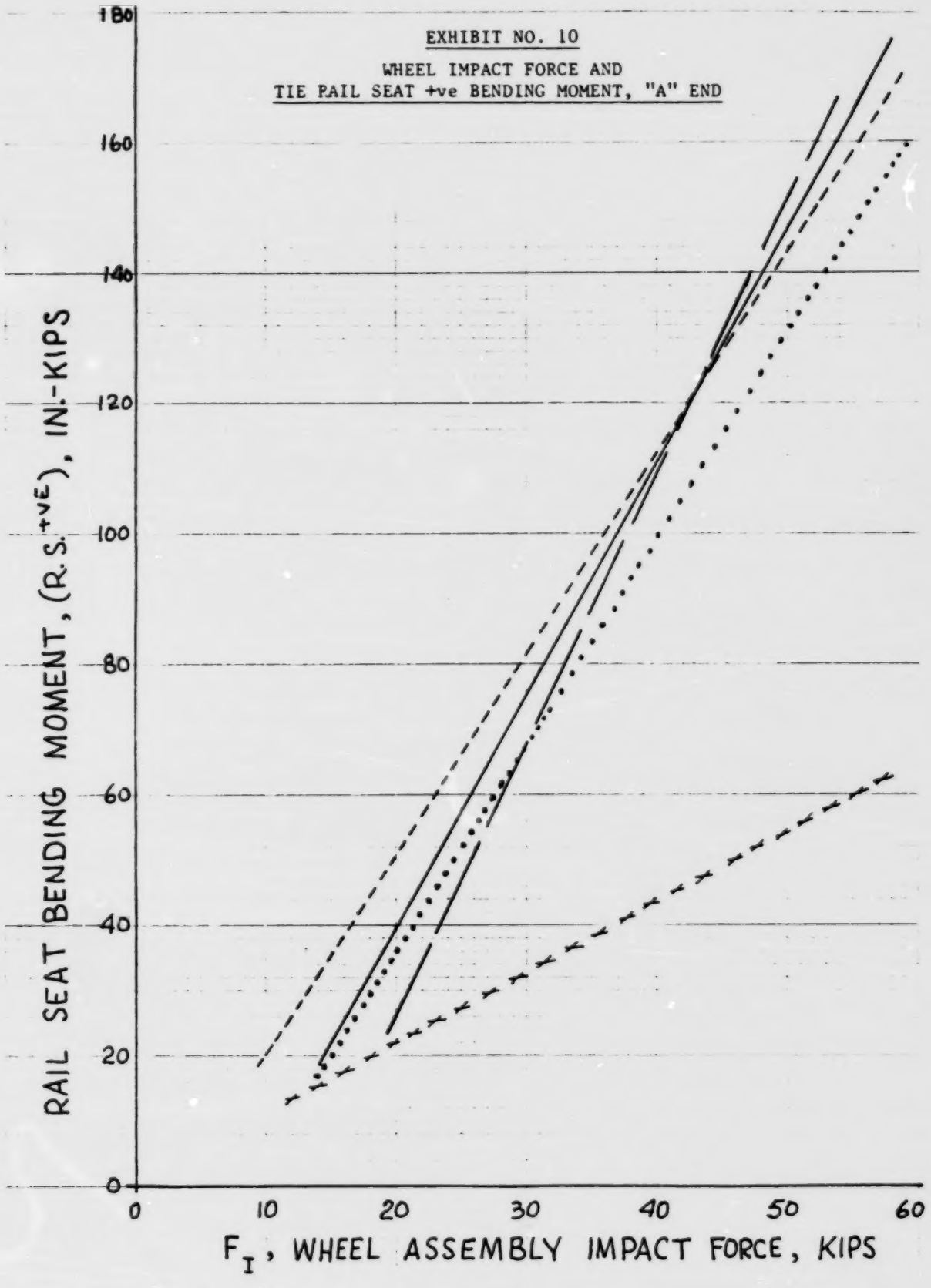

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EXHIBIT NO. 11

WHEEL IMPACT FORCE AND
TIE CENTER BENDING, -ve

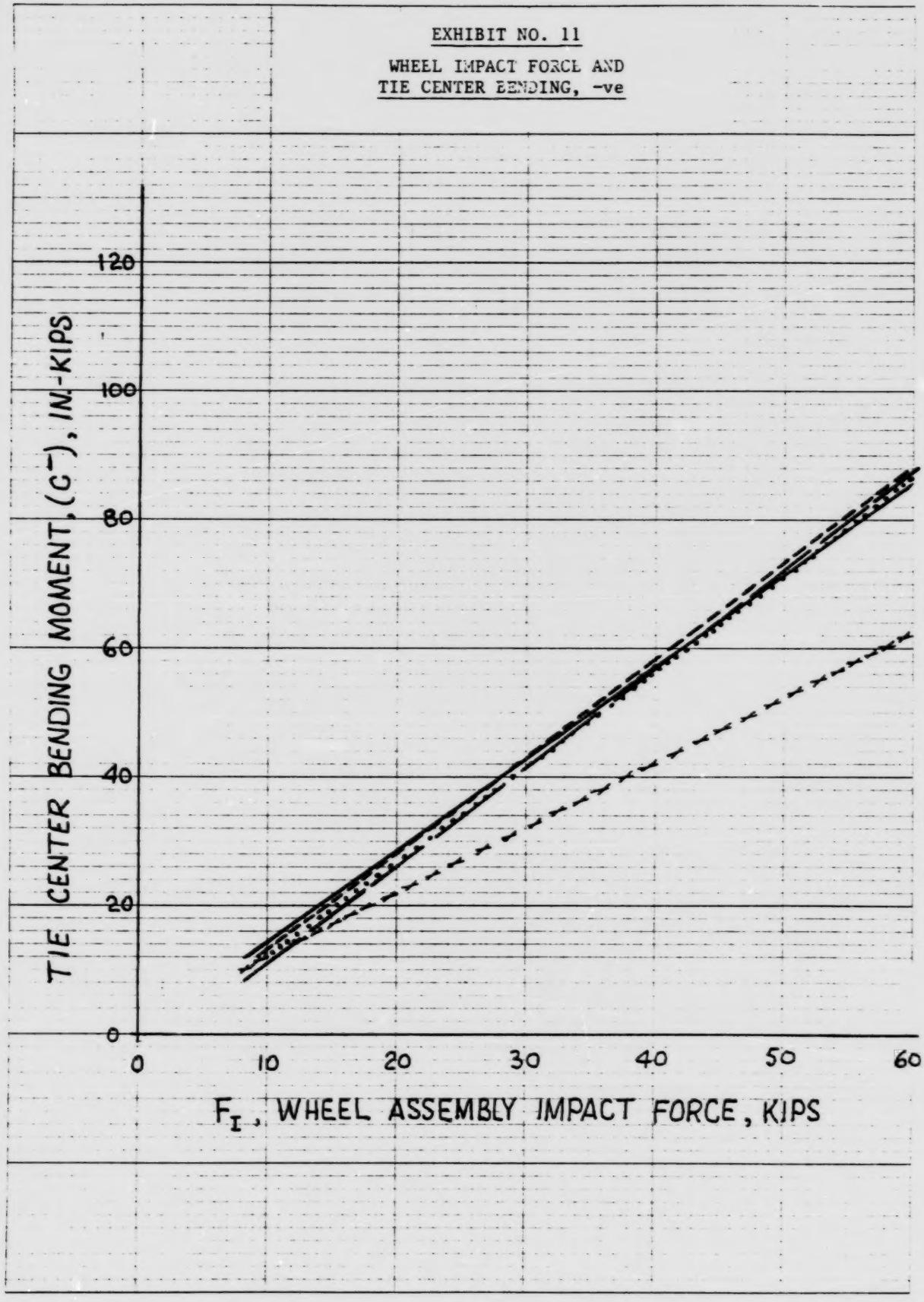

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TABLE NO. 2

Ratios: $\frac{\text{Bending Moment at 60 kip } F_I}{\text{Av. Static First Crack Bending Moment}}$

Bending Mode:		RS +ve "B" End	RS -ve "B" End	RS +ve "A" End	C -ve
CN60A Tie	Pad E	0.53	0.46	0.16	0.34
	Pad D	0.80	0.74	0.43	0.48
	Pads A,B,C	0.80	0.86	0.48	0.48
CN60B Tie	Pad E	0.61	0.31	0.18	0.26
	Pad D	0.91	0.50	0.48	0.36
	Pads A,B,C	0.91	0.50	0.48	0.36

For a "zero-crack" environment, impact force attenuation to the levels obtained by Pad E is highly desirable. In the RS +ve bending mode, Pads A, B, C and D provided a lower margin of safety for the CN60B tie from isolated impact forces exceeding 60 kips. Field measurements indicate frequency of impact forces exceeding 60 kips are rare and therefore use of Pads A, B, C and D would not contribute to rail seat +ve bending mode cracks. However, stiffer pads permit a larger number of high frequency stress reversals so that the number of cycles of bending moment at the minimum fatigue moment level for first micro-crack will be accumulated over a shorter time span than with a soft pad. Over the long-term, use of a softer pad would extend the life of the concrete tie. The same comment applies to rail seat -ve moment.

The minimum required fatigue moment levels for the CN60A concrete tie to initiate micro-cracks from CN laboratory tests were:

RS^{+ve} + 190, RS^{-ve} - 78, C^{-ve} - 70 in. kips

6. GENERAL DISCUSSION

For the short three-tie stub test track, the wheel/rail impact force was not significantly attenuated by the use of softer rail-tie pads. At 3 inch wheel drop height, impact forces ranged from 52.5 to 60 kips. Between 32 and 40% of the wheel/rail impact force went directly into the rail seat of the tie immediately below the impact point. The very soft pad (with a stiffness of 0.324 million lbs./in.) did reduce the bending moment levels in the tie. In comparison with moments produced with the four other stiffer pads, attenuation at the impacted end of tie was 33% for rail seat positive moment, and 42 to 47% for rail seat negative moment. At the opposite end of the tie, attenuation ranged from 62 to 67% for rail seat positive moment. For tie center negative moment, attenuation was in the order of 30% with the very soft pad.

It is clear that an insignificant attenuation can be achieved with pads that are only 5 mm thick. The very soft pad with thickness of 9 mm did provide the tie with some protection, but it is not known at this time if such a pad would survive for any length of time on track. It would also be incompatible with the current rail-tie fastening system.

While softer pads and redesigned rail fastening systems hold promise for the future, the most significant gain could be made if track impact loading could be reduced through improved wheel and rail maintenance. This is easier said than done, but with wheel impact loading detectors now beginning to document the track loading environment, it is almost certain that inroads in this area will be made in future.

It is significant to note that the CN60A concrete test tie remained uncracked after being subjected to hundreds of wheel/rail impact loads ranging from 20 to 65 kips. The concrete tie is certainly no weakling. In the continuing search for better track structure there are two objectives: to maximize component life, and to minimize component cost. It is now realized that, for optimum concrete tie design, the rail fastening system, including clips, pads and insulators, has a very significant role to play. Improvements are almost certain to evolve in future.

Two Appendices have been attached to this report. Appendix A includes individual plots of wheelset drop test data. This information documents all the test results. Appendix B provides an outline of the drop tests performed and the difficulties encountered from date work on this project was started. Although none of the data accumulated from initial tests could be used because recording frequencies were not high enough, valuable experience was gained. It is important to document what did not work properly in order that the same mistakes are not repeated in future.

APPENDIX A

INDIVIDUAL PLOTS OF DROP TEST DATA COVERING EACH TIE PAD

Note: F_I = Impact force generated at wheel/rail interface (measured)

F_R = That portion of the impact force transmitted by the rail to the outboard ties (measured)

F_T = That portion of the impact force transmitted directly into the rail seat of the central tie.

$$(F_T = F_I - F_R)$$

EXHIBIT NO. 12a

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL/RAIL IMPACT, PAD A

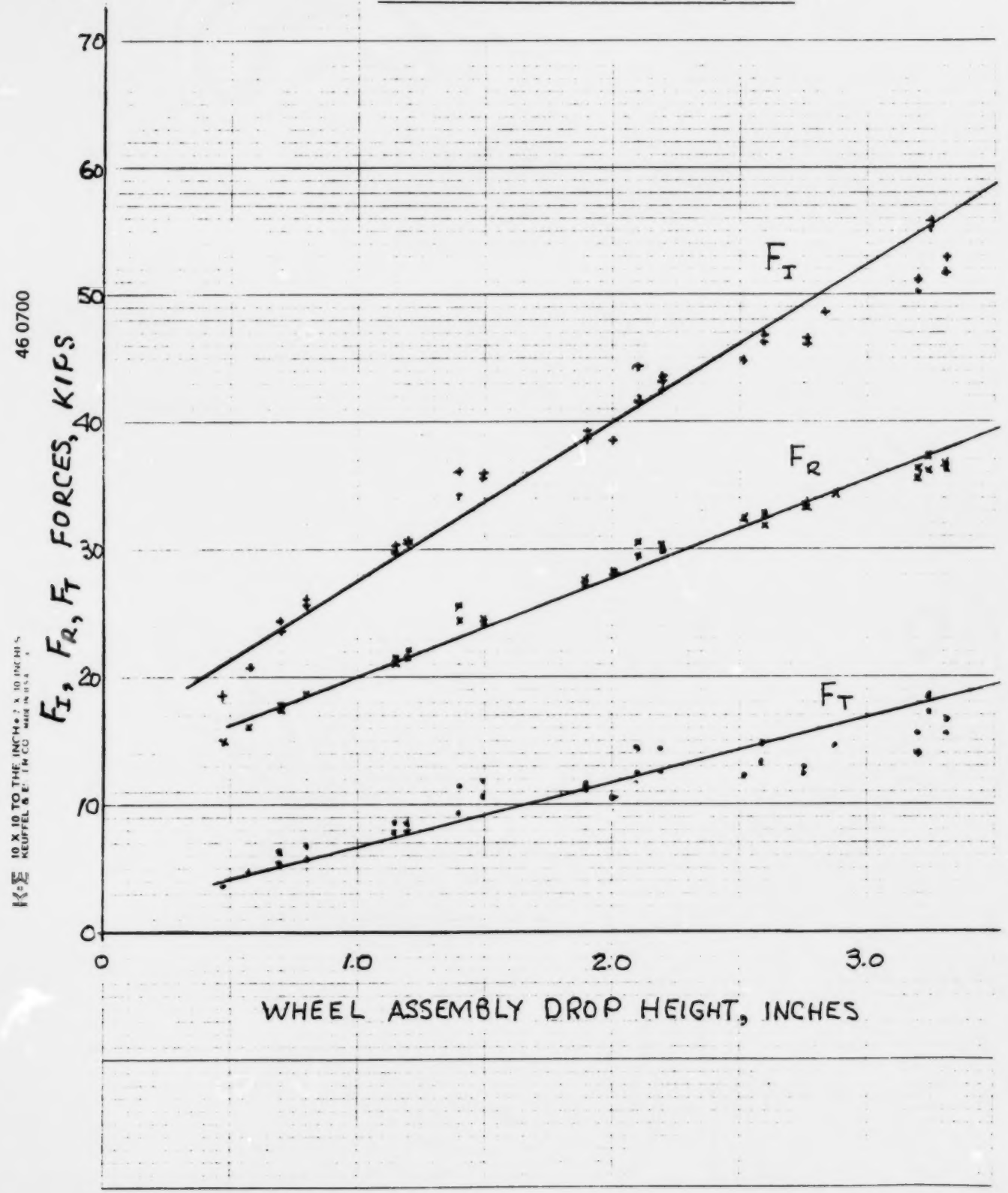
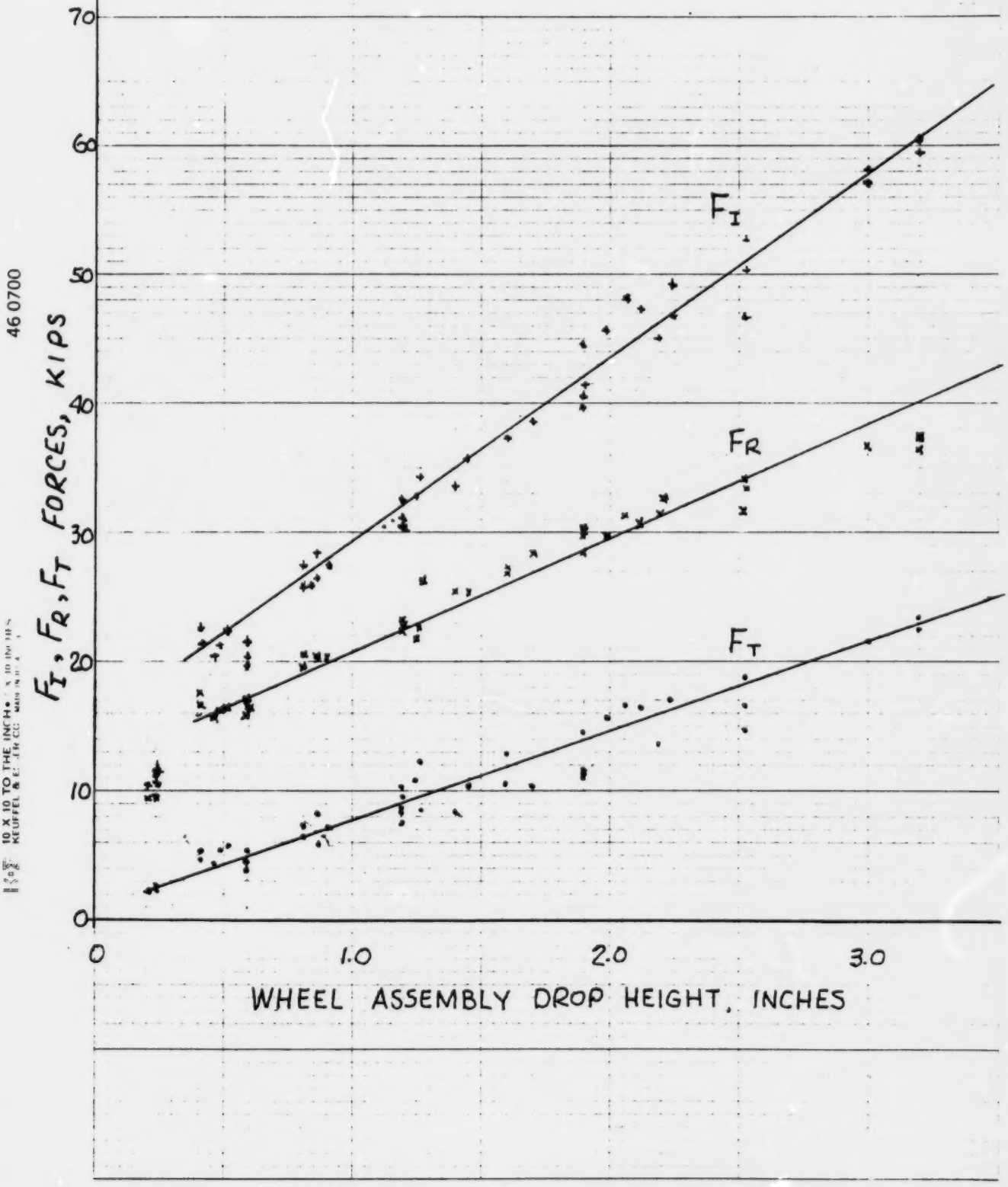


EXHIBIT NO. 12b

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL/RAIL IMPACT, PAD B



46 0700
10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 12c

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL/RAIL IMPACT, PAD C

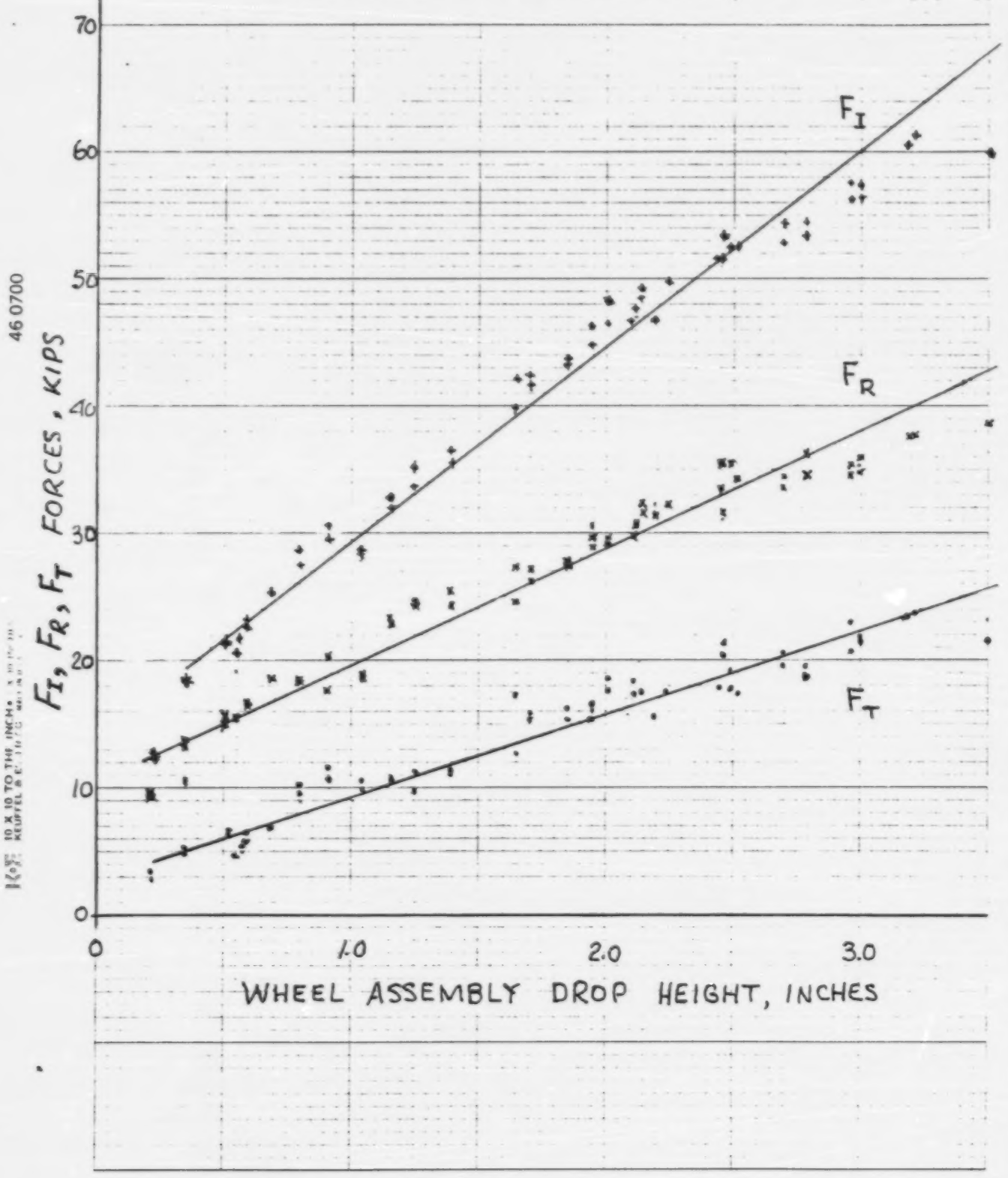


EXHIBIT NO. 12d

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL/RAIL IMPACT, PAD D

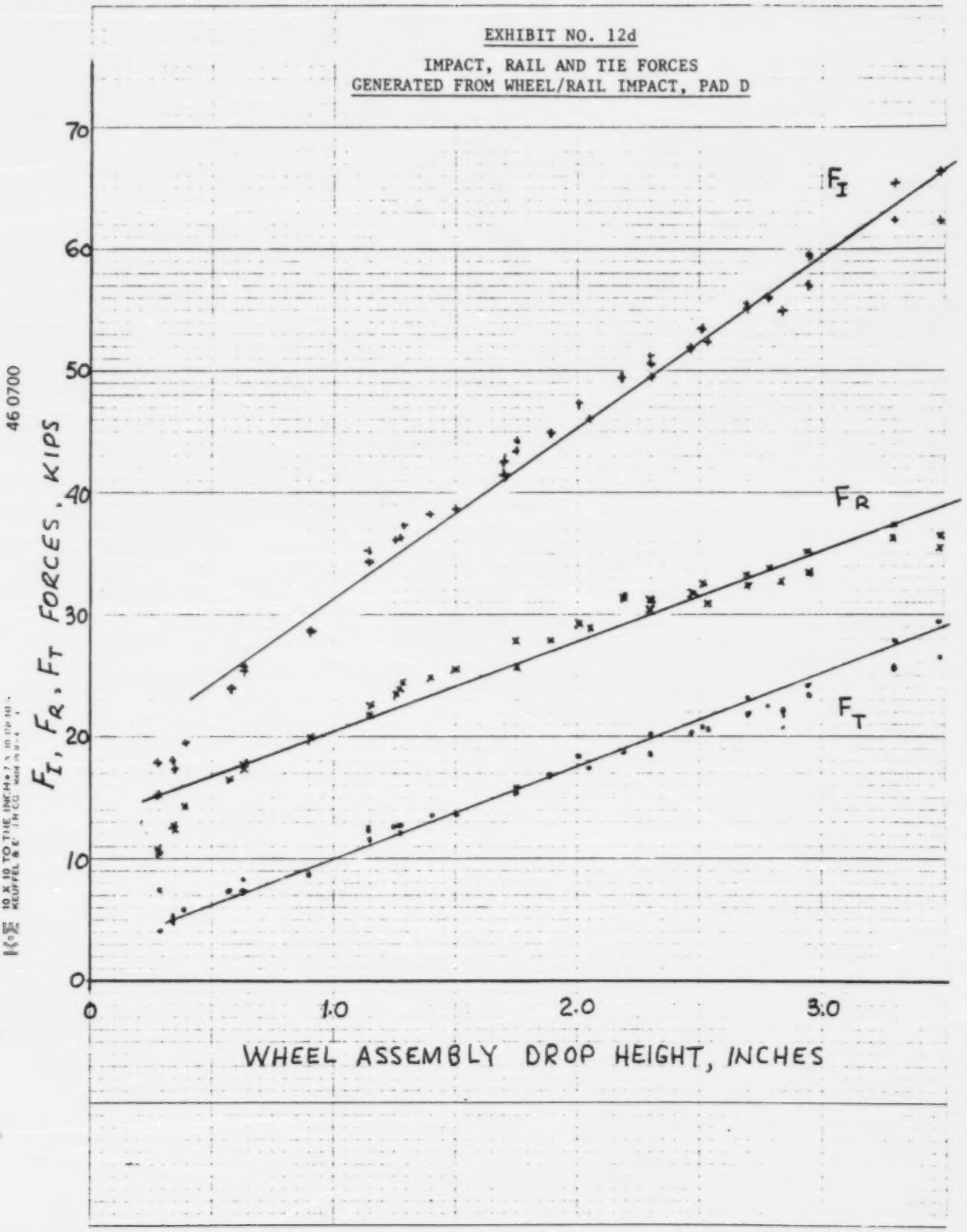


EXHIBIT NO. 12e

IMPACT, RAIL AND TIE FORCES
GENERATED FROM WHEEL/RAIL IMPACT, PAD E

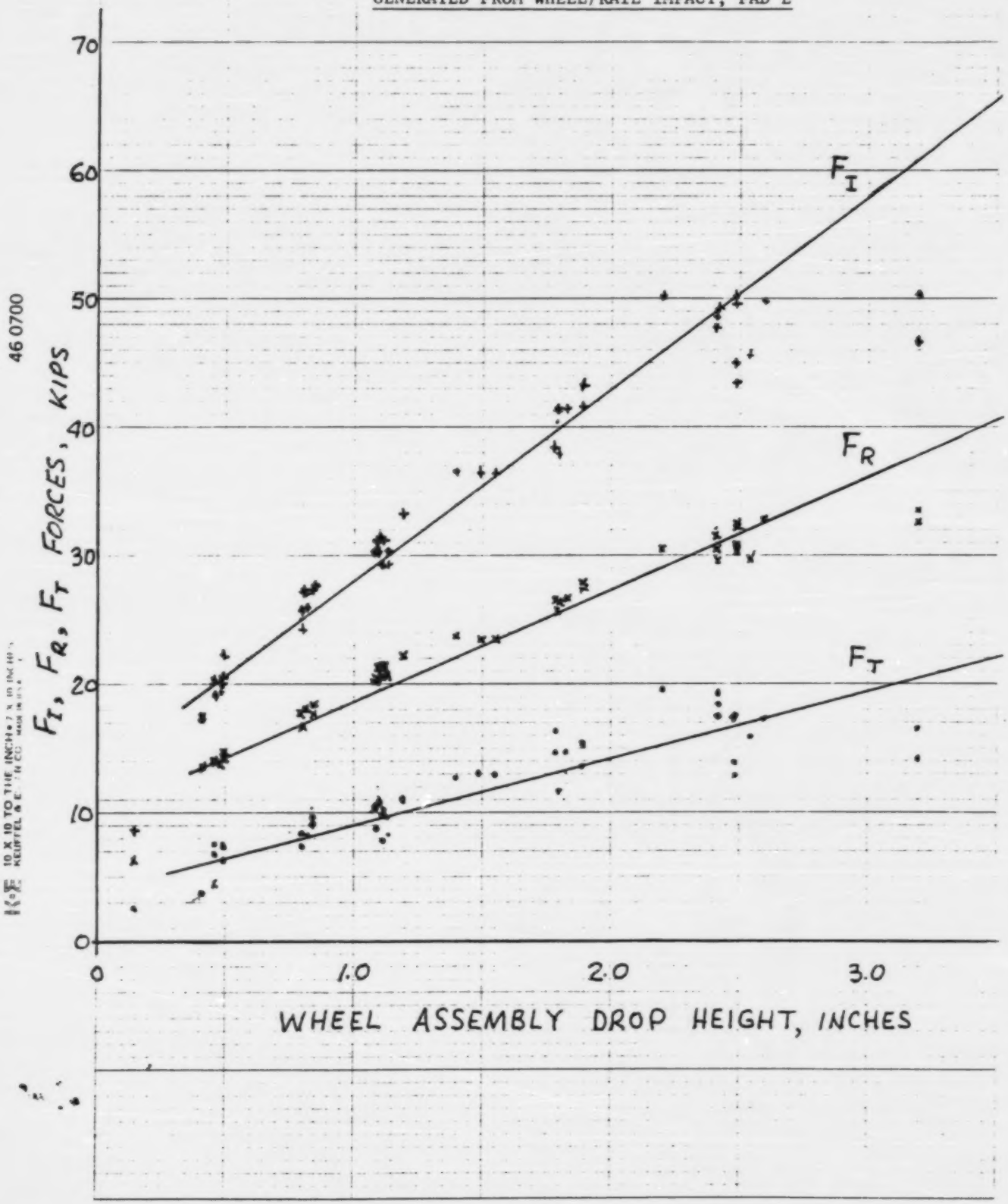
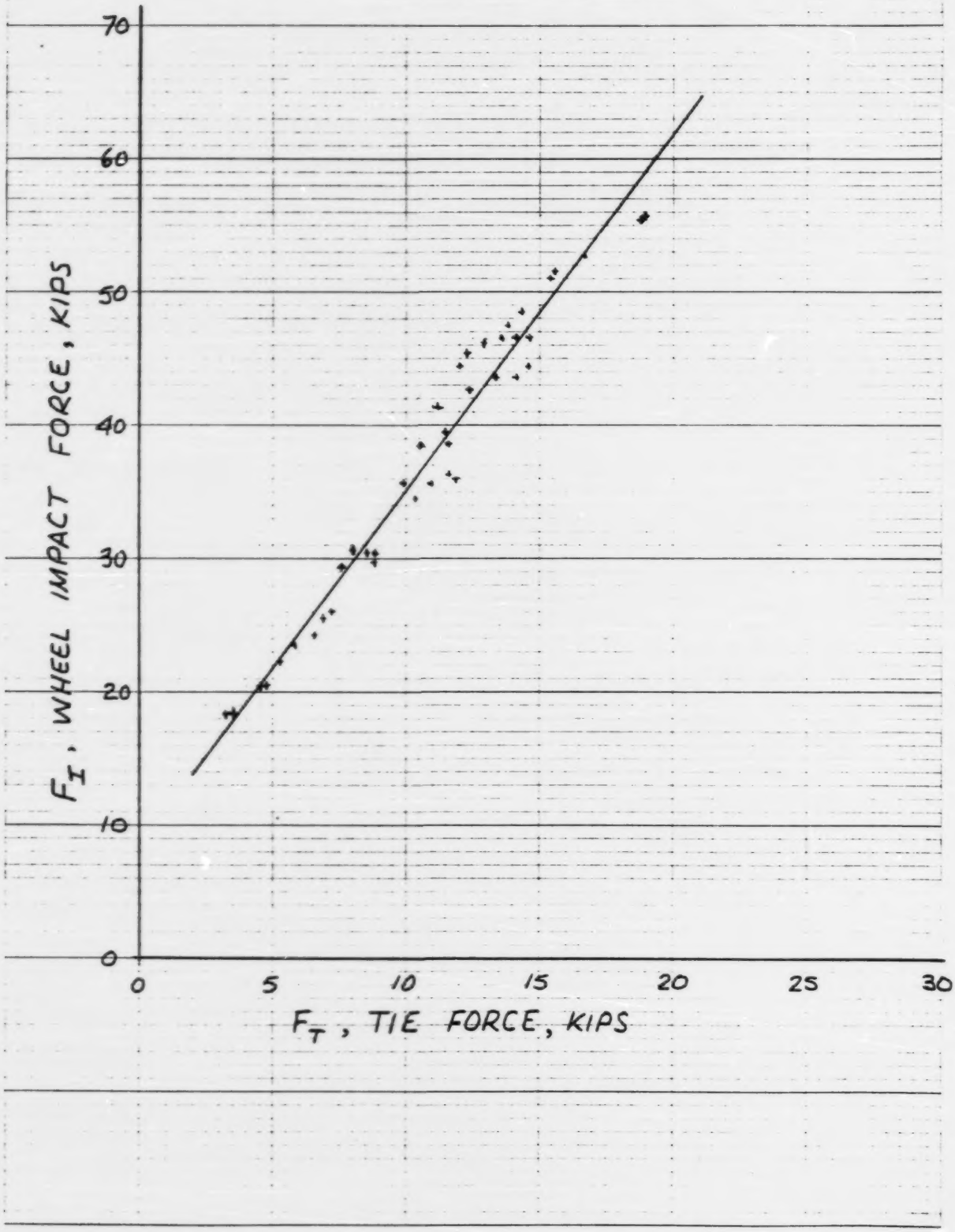


EXHIBIT NO. 13a

CONCRETE TIE FORCE AND
WHEEL IMPACT FORCE, PAD A



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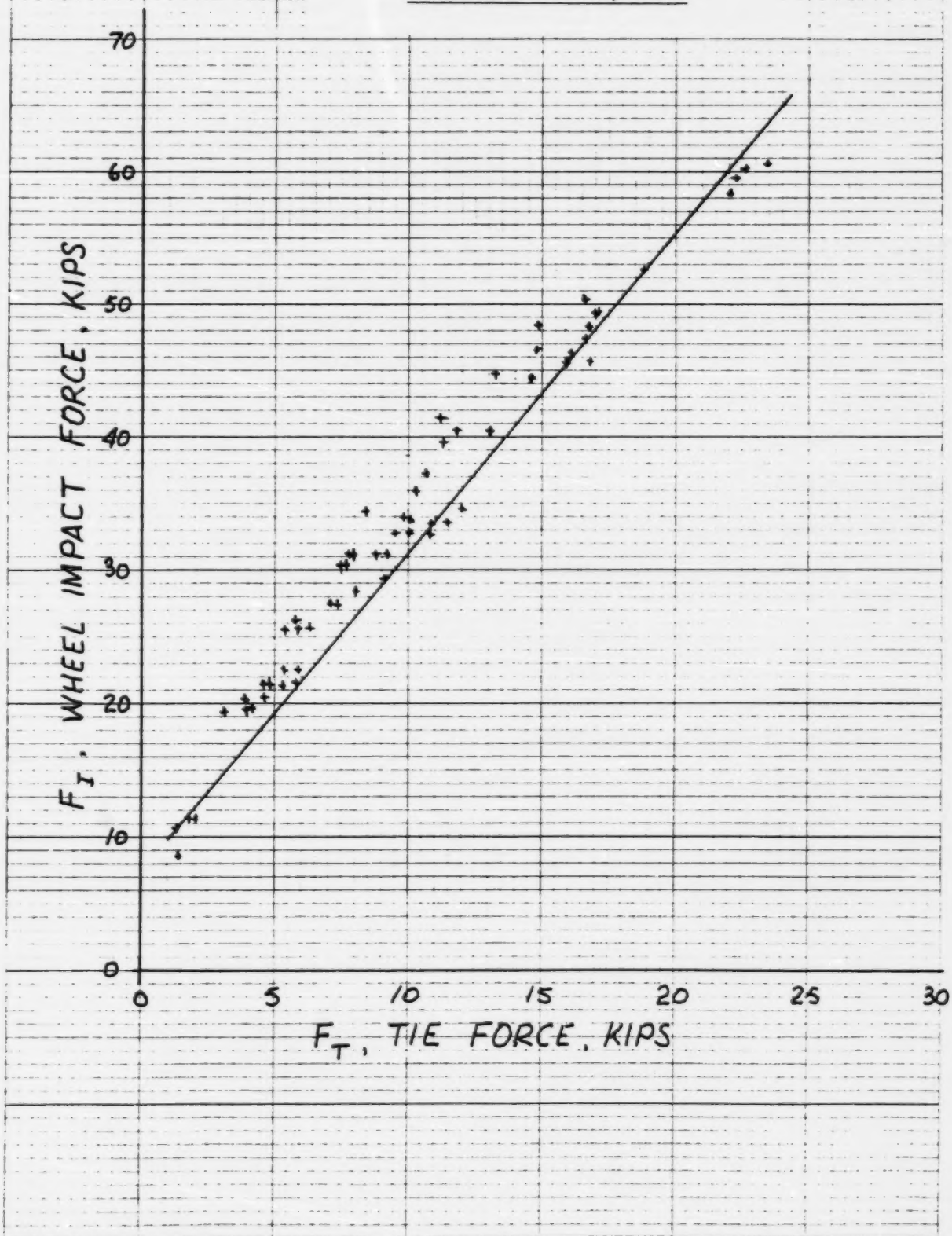
10 X 10 TO THE INCH

EXHIBIT NO. 13b

CONCRETE TIE FORCE AND
WHEEL IMPACT FORCE, PAD B

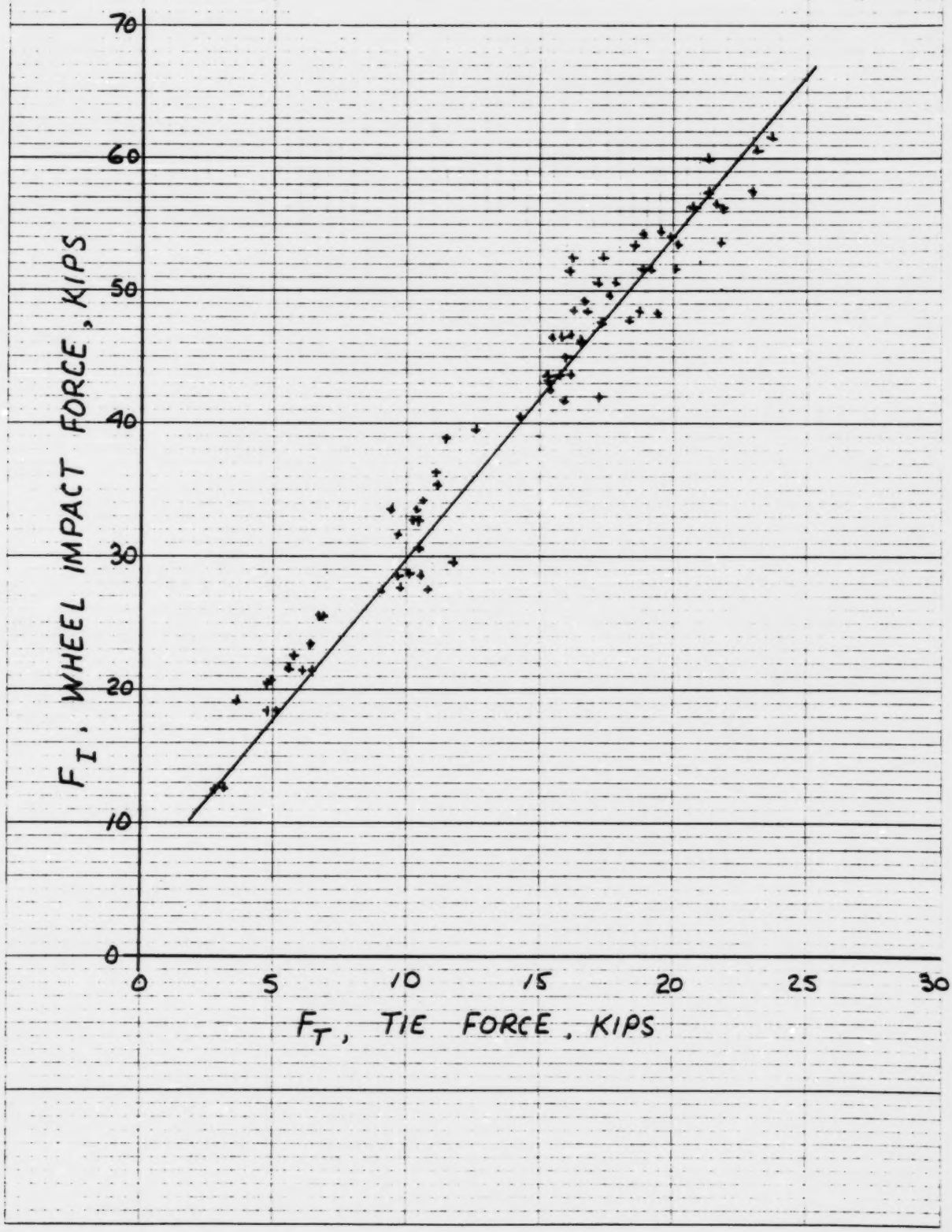


46 0700

10 X 10 TO THE INCH • 7 X 10 IN. •
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT NO. 13c

CONCRETE TIE FORCE AND
WHEEL IMPACT FORCE, PAD C

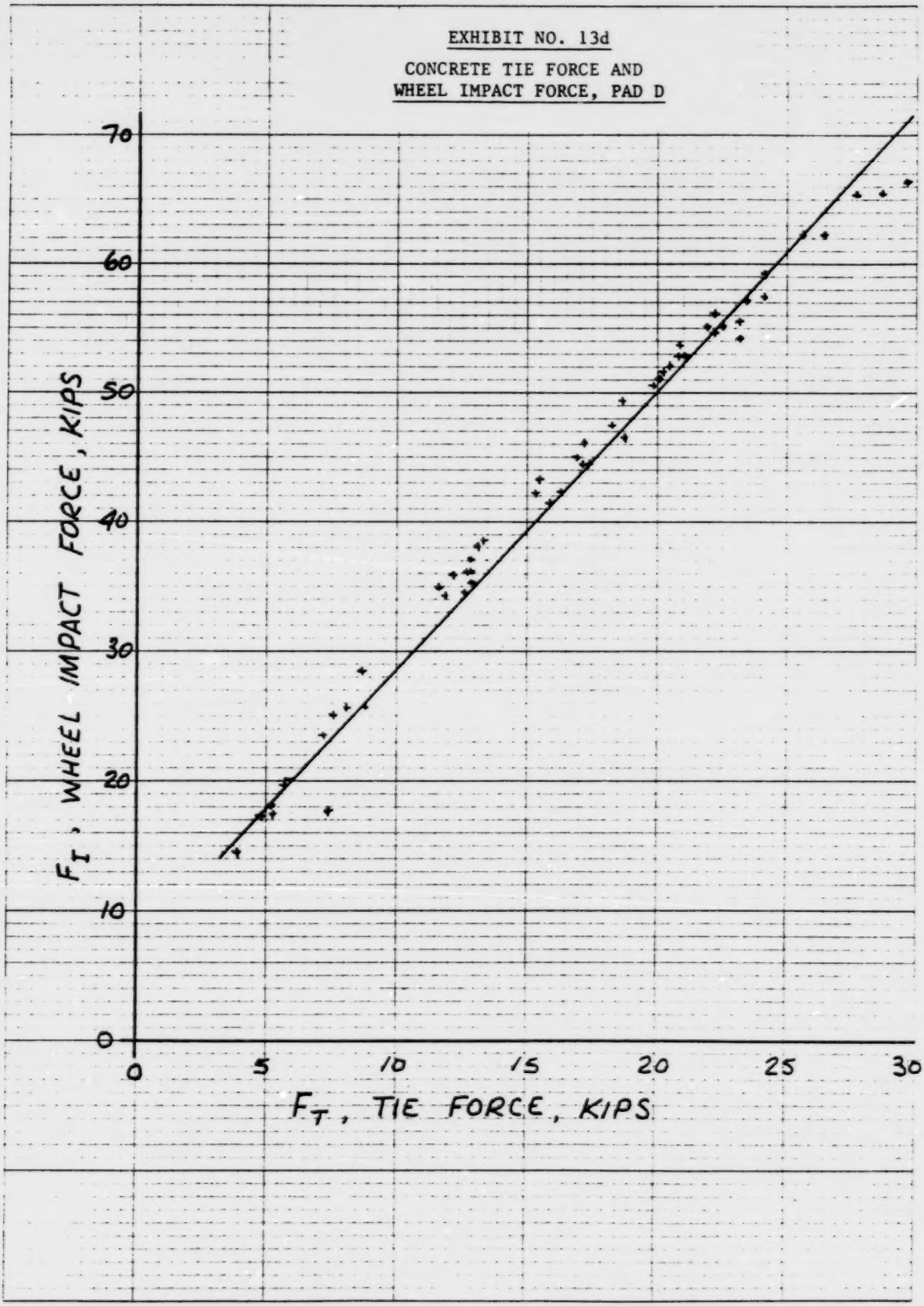


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 13d

CONCRETE TIE FORCE AND
WHEEL IMPACT FORCE, PAD D



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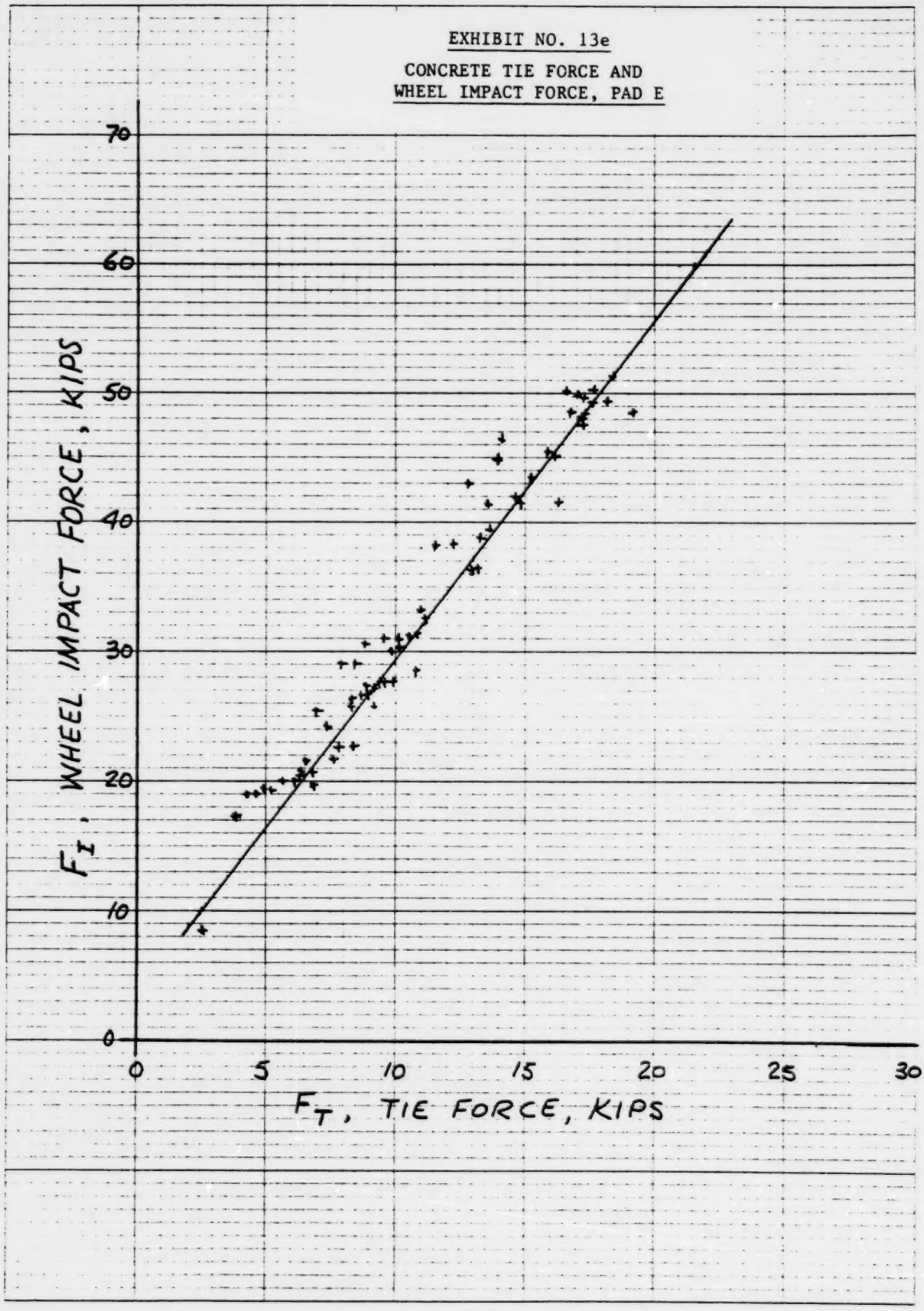
KEUFFEL & ESSER CO

EXHIBIT NO. 13e

CONCRETE TIE FORCE AND
WHEEL IMPACT FORCE, PAD E



46 0700

10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT NO. 14a

TIE FORCE AND RAIL SEAT (+ve)
BENDING MOMENT "B" END OF TIE, PAD A

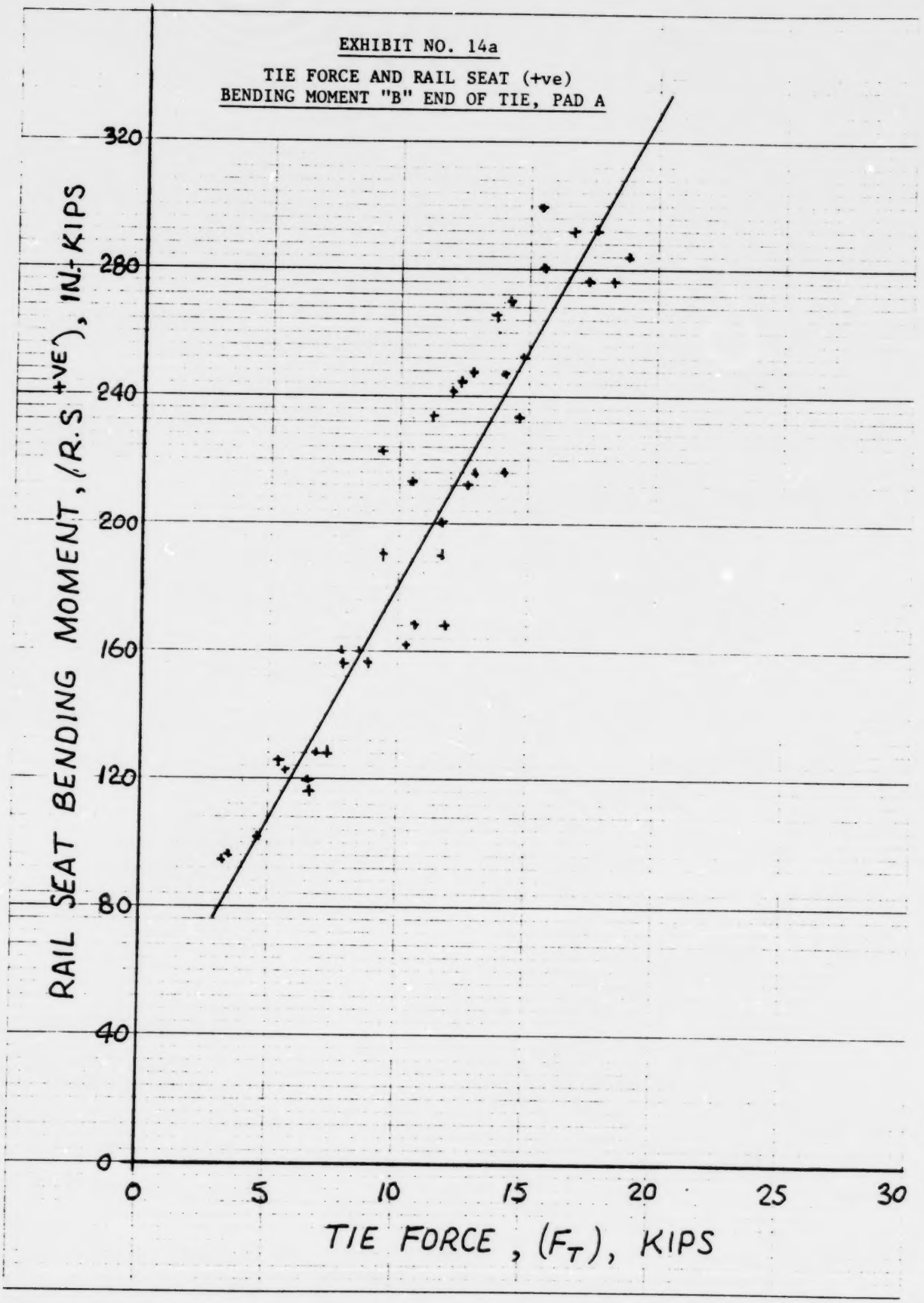


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EXHIBIT NO. 14b

TIE FORCE AND RAIL SEAT (+ve) BENDING MOMENT, PAD B

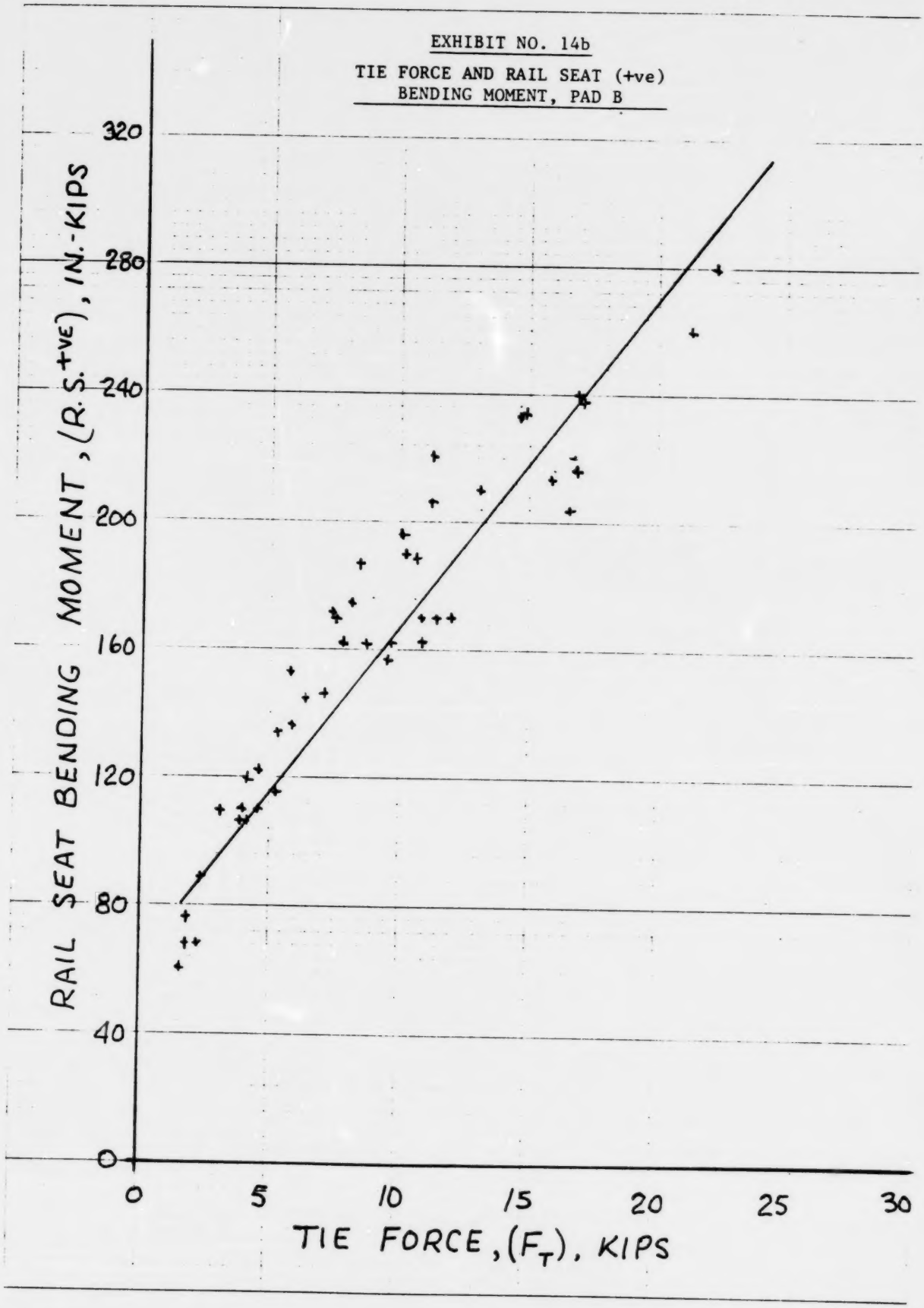

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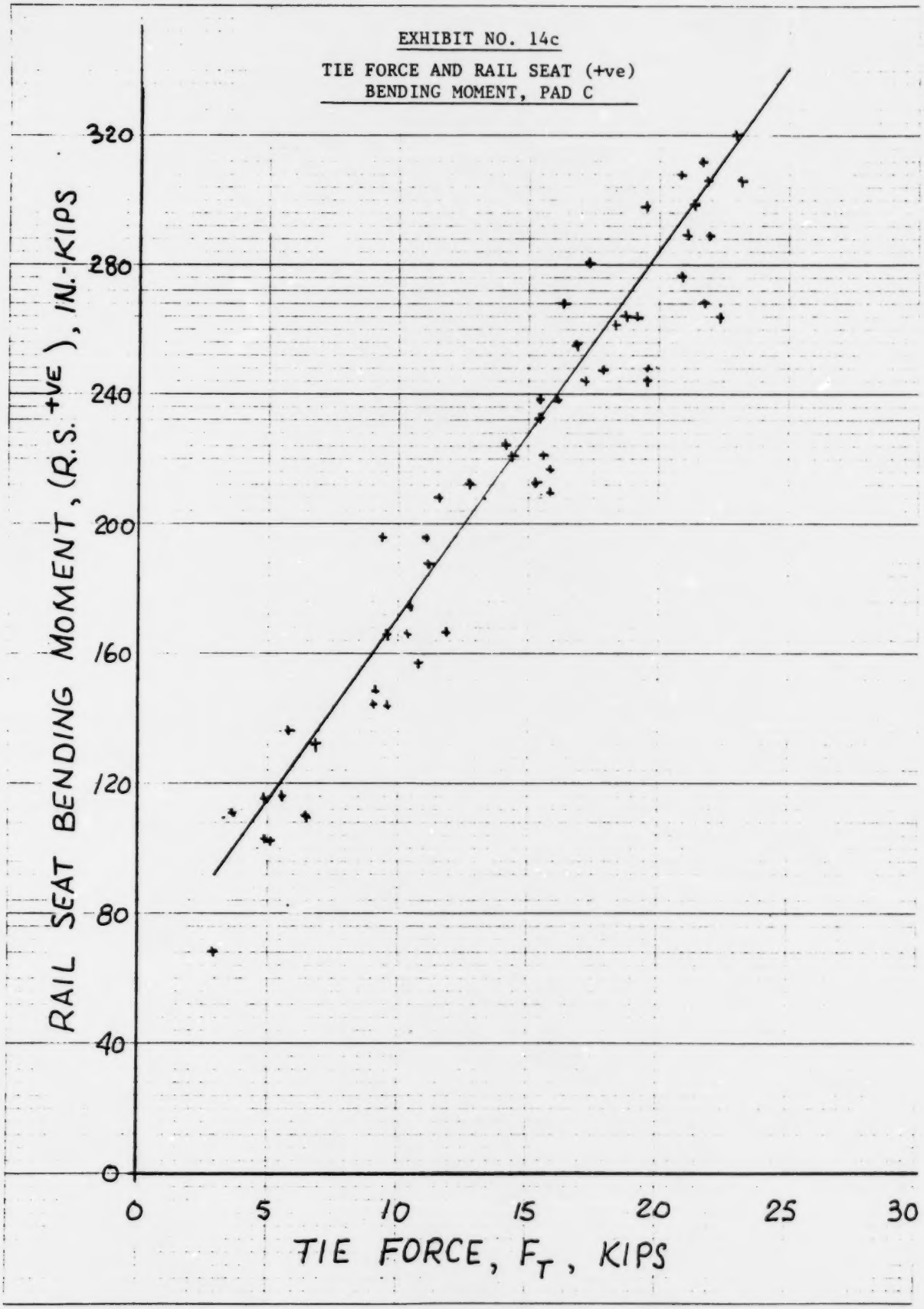
EXHIBIT NO. 14c

TIE FORCE AND RAIL SEAT (+ve) BENDING MOMENT, PAD C

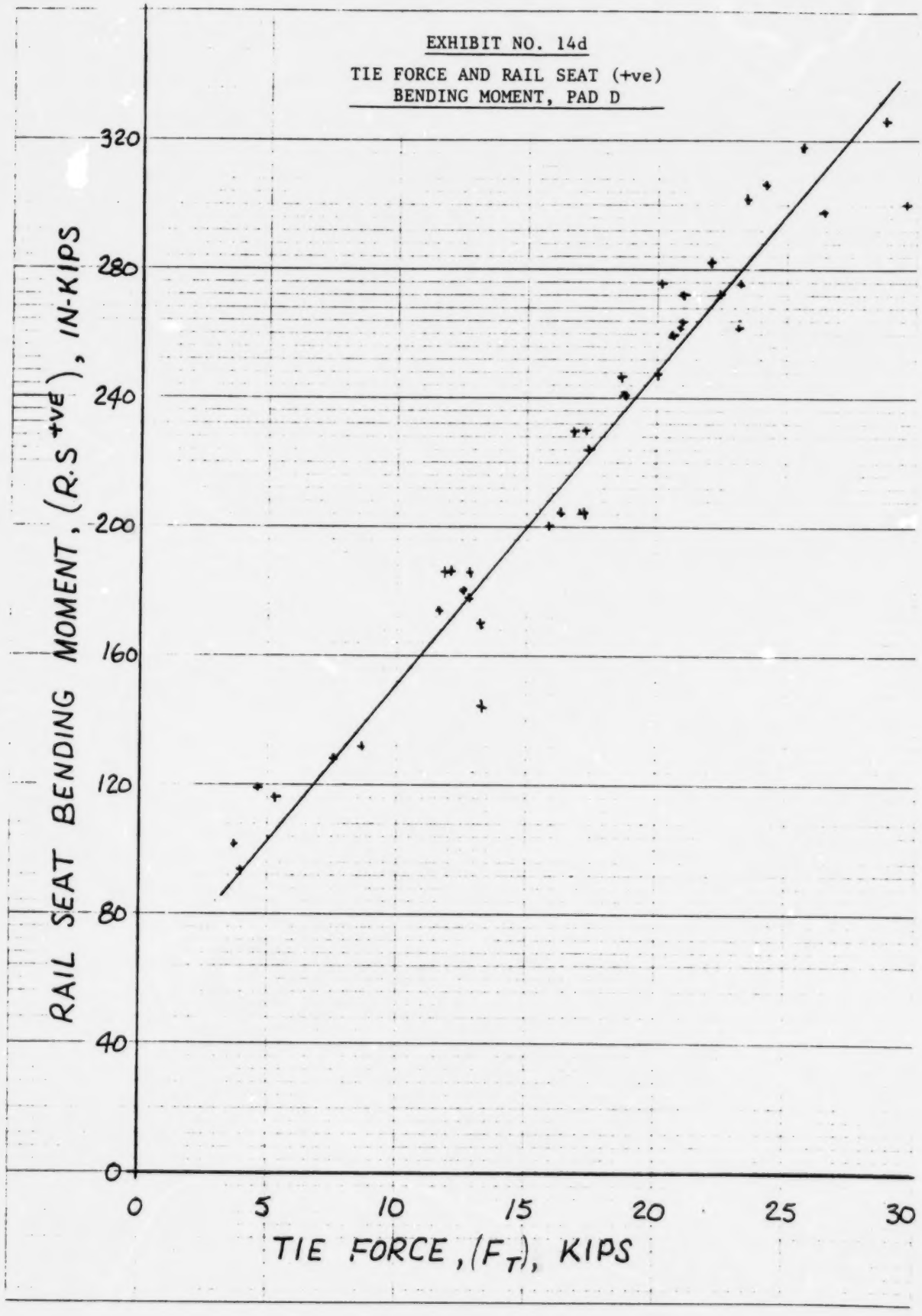


46 0700

10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT NO. 14d

TIE FORCE AND RAIL SEAT (+ve) BENDING MOMENT, PAD D

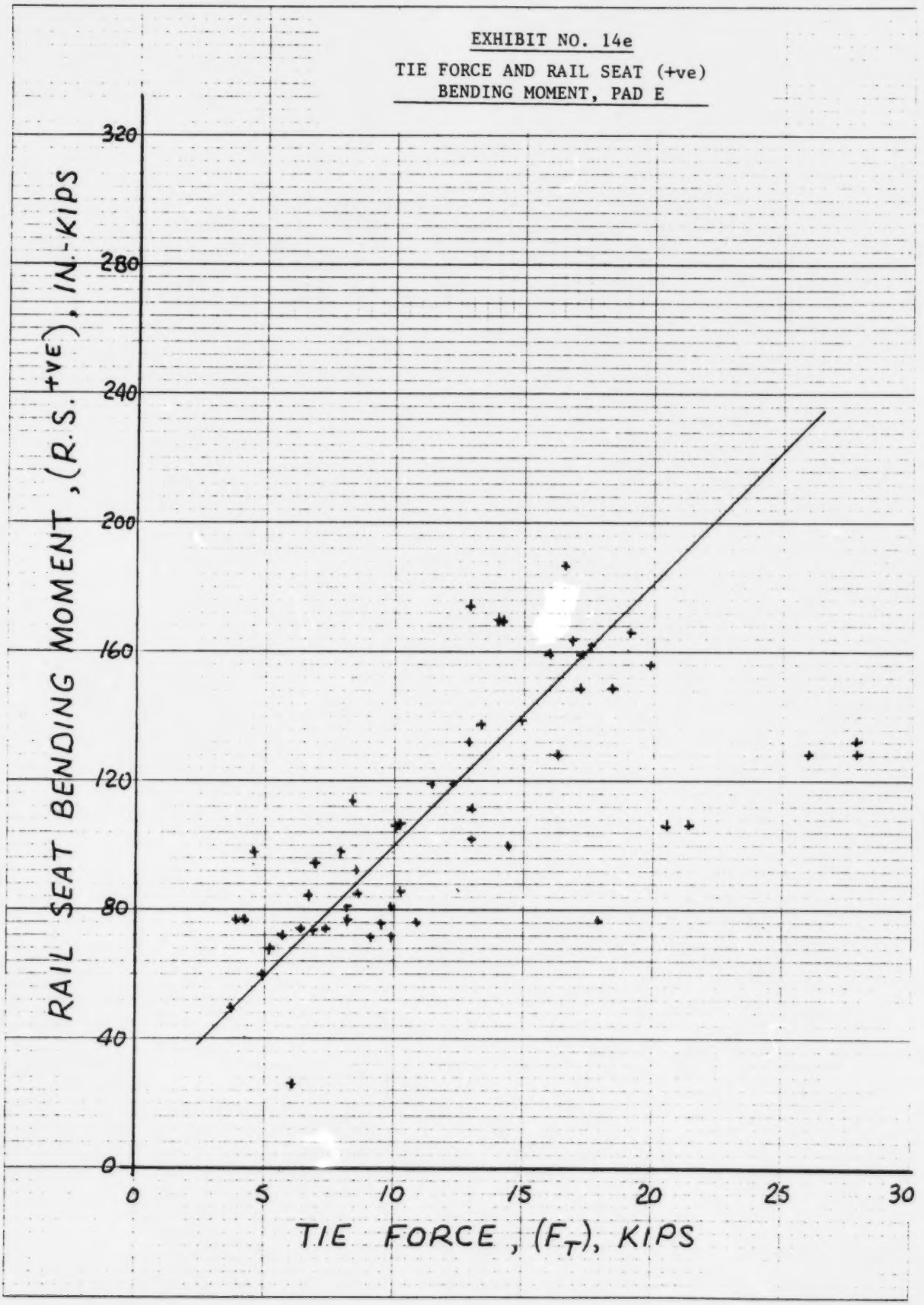


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER

EXHIBIT NO. 14e

TIE FORCE AND RAIL SEAT (+ve) BENDING MOMENT, PAD E



46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 15a

TIE FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, PAD A

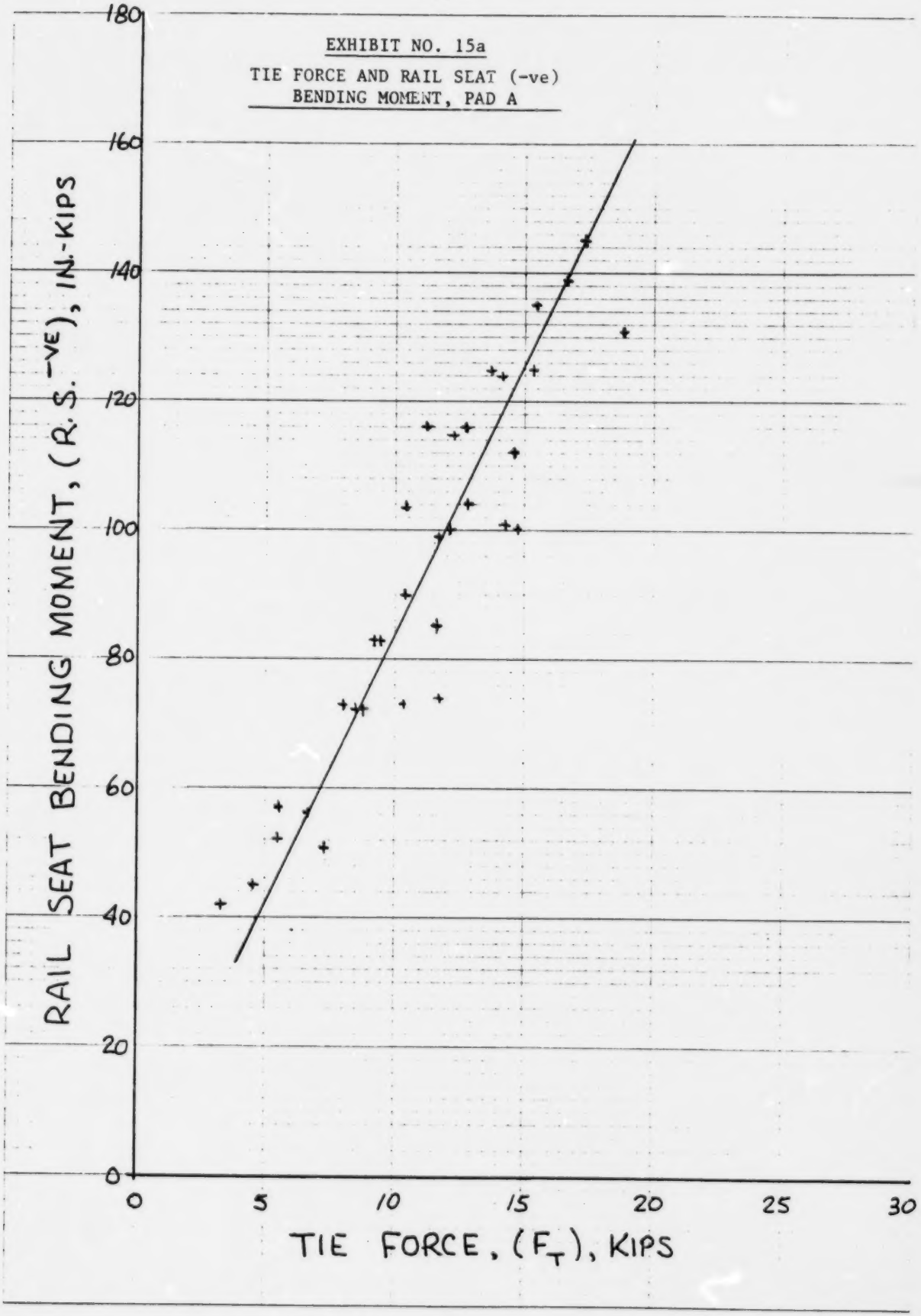


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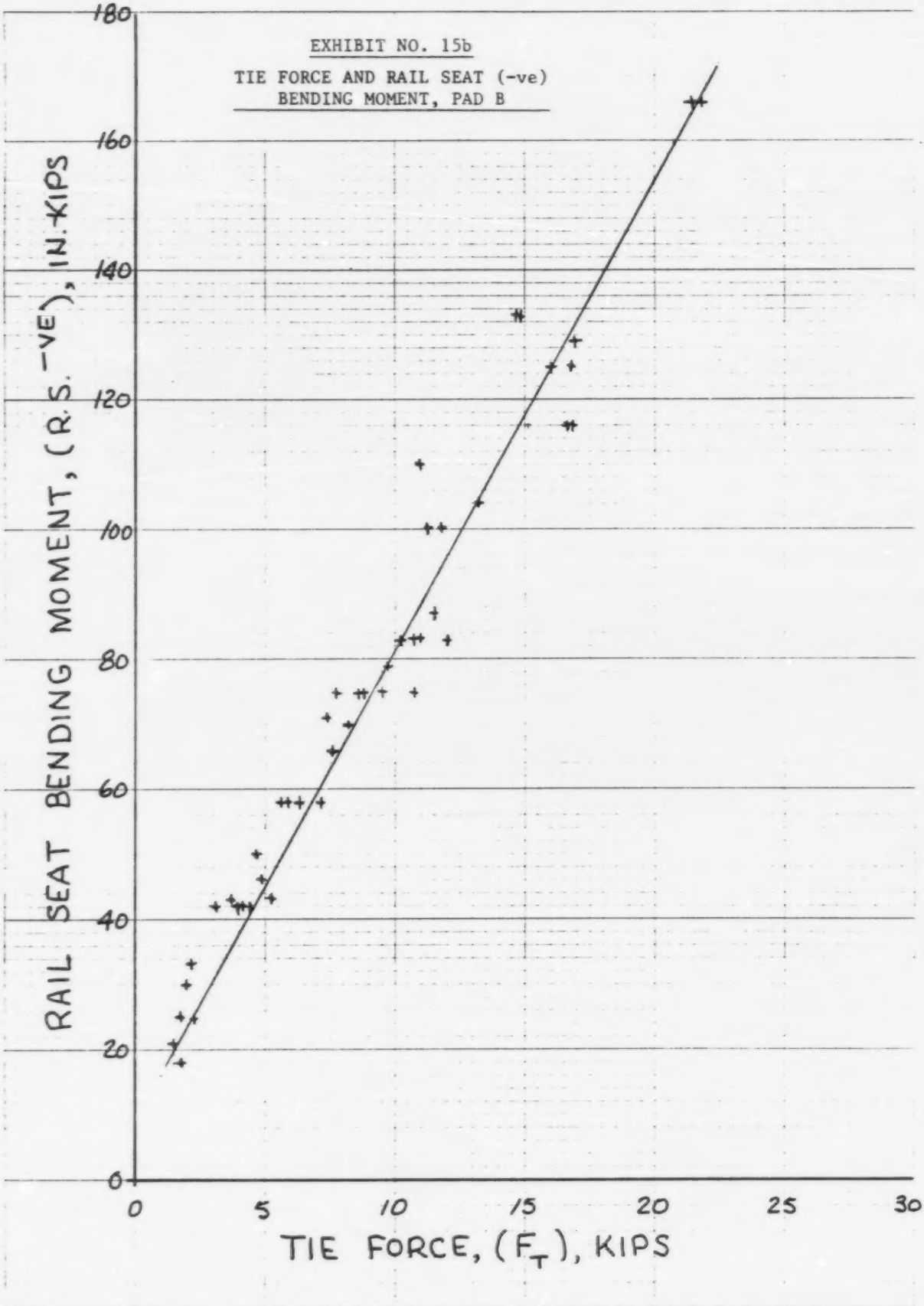
EXHIBIT NO. 15b

TIE FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, PAD B



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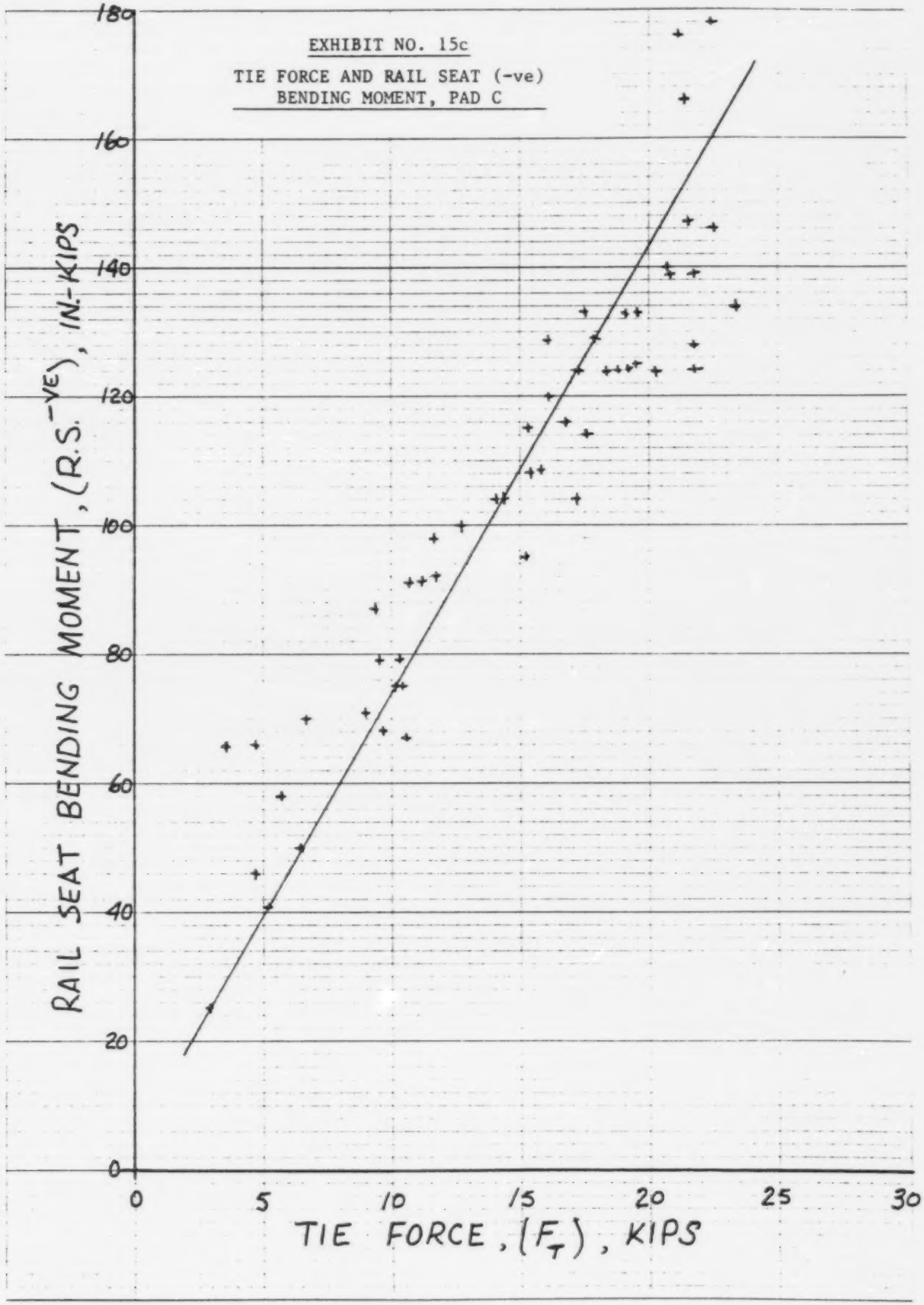
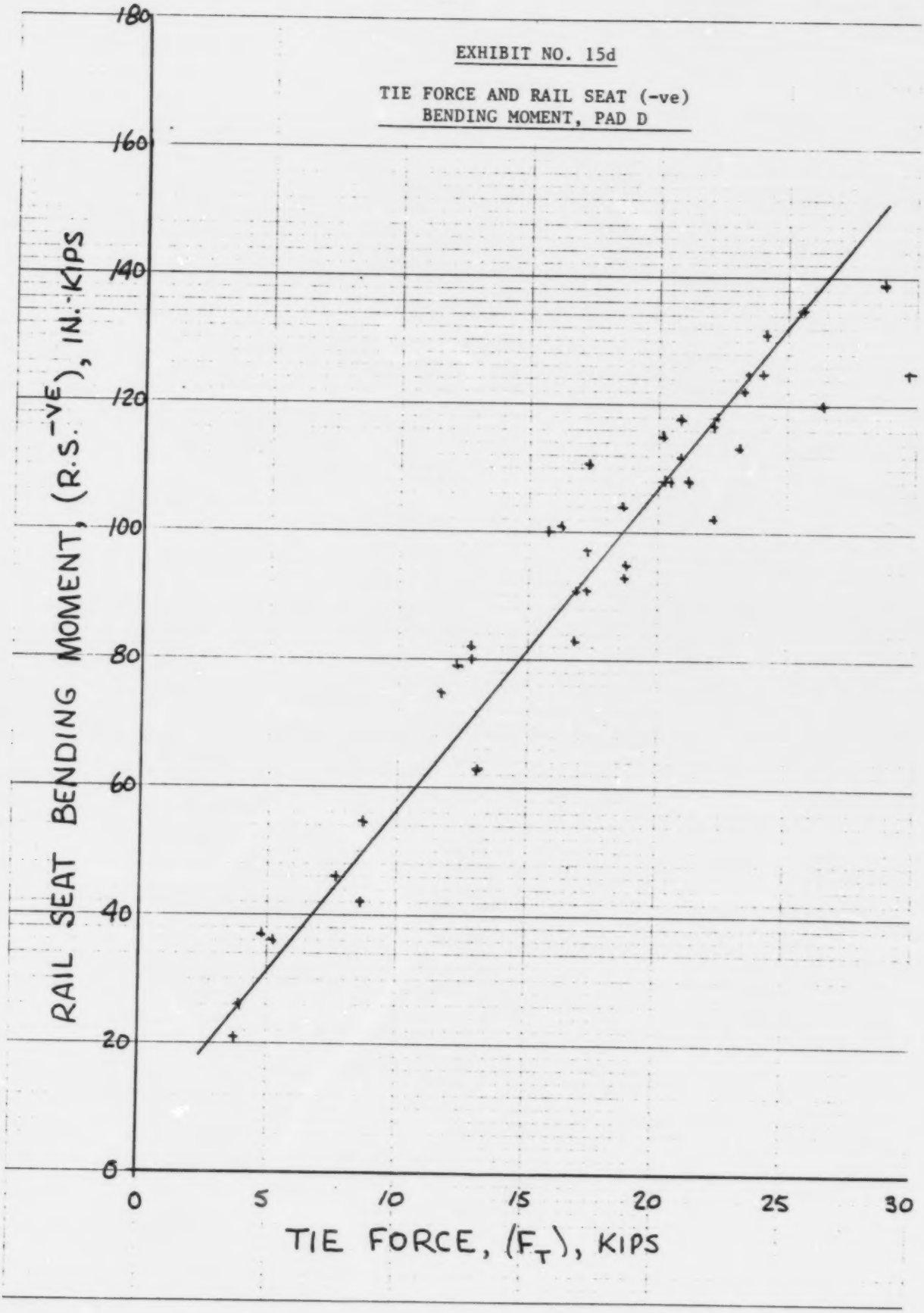


EXHIBIT NO. 15c
TIE FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, PAD C
RAIL SEAT BENDING MOMENT, (R.S.-VE), IN.-KIPS
TIE FORCE, (F_T), KIPS
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

46 0700

EXHIBIT NO. 15d

TIE FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, PAD D



46 0700

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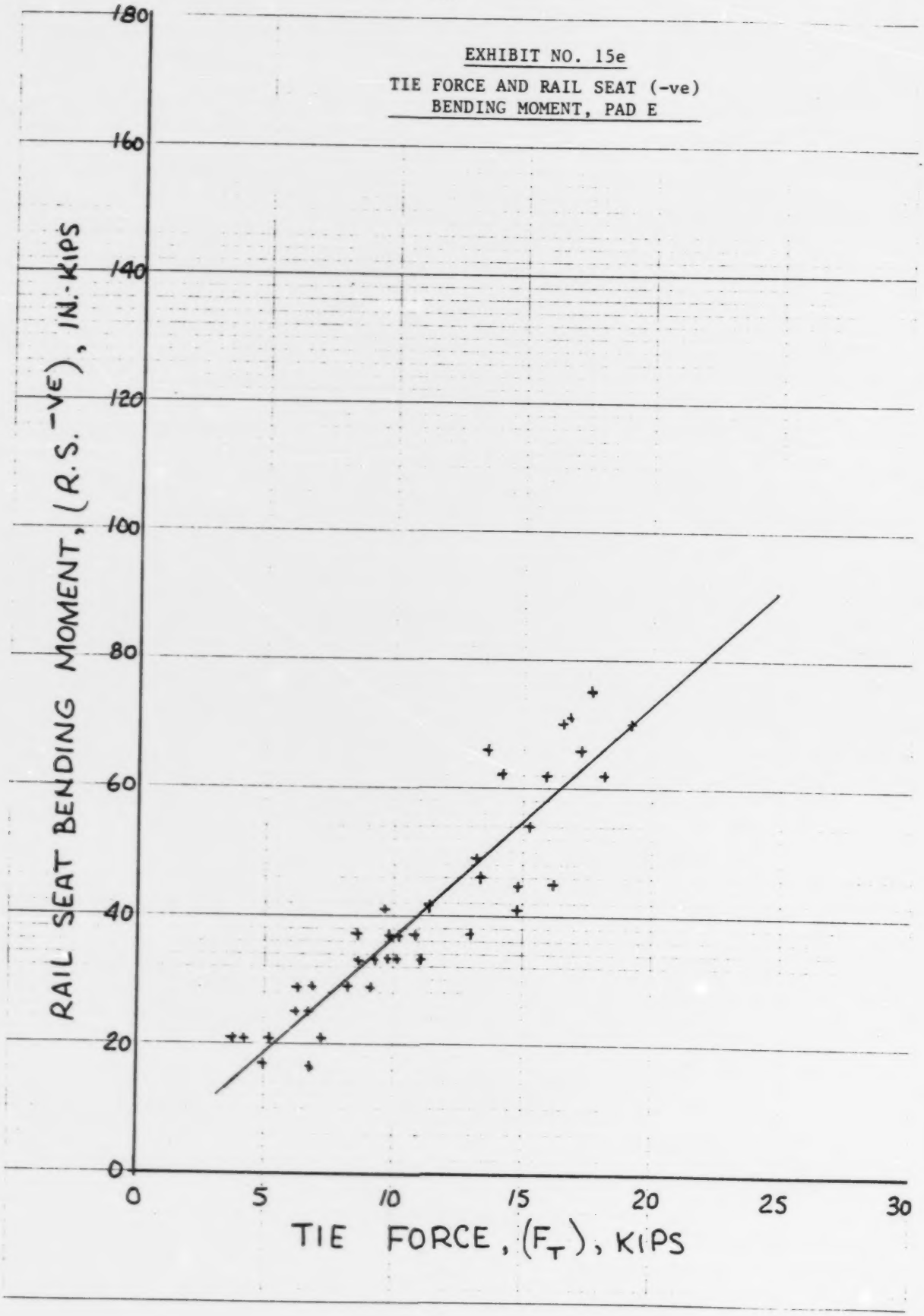
KEUFFEL & ESSER CO.

EXHIBIT NO. 15e

TIE FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, PAD E

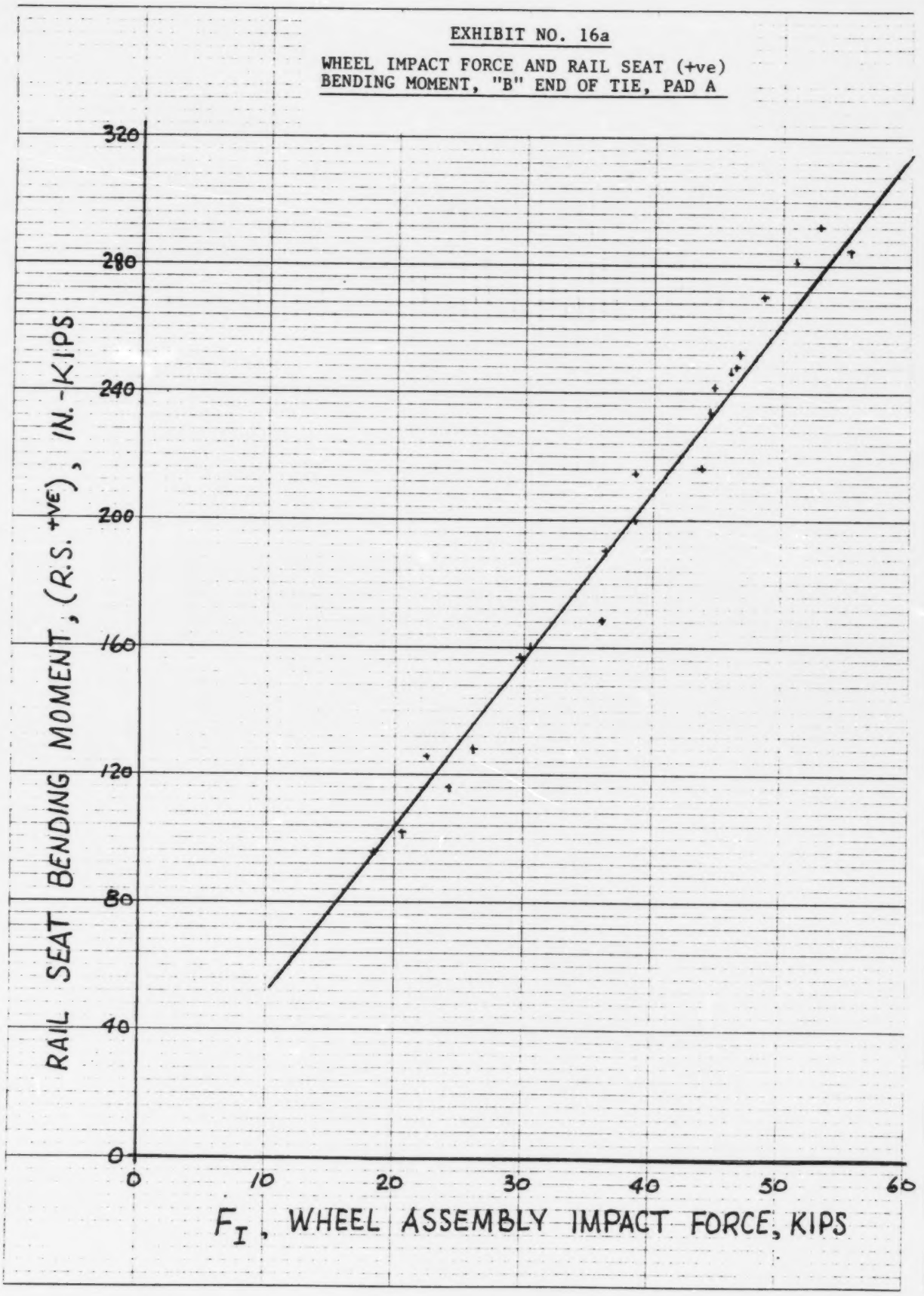


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 16a

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "B" END OF TIE, PAD A



46 0700

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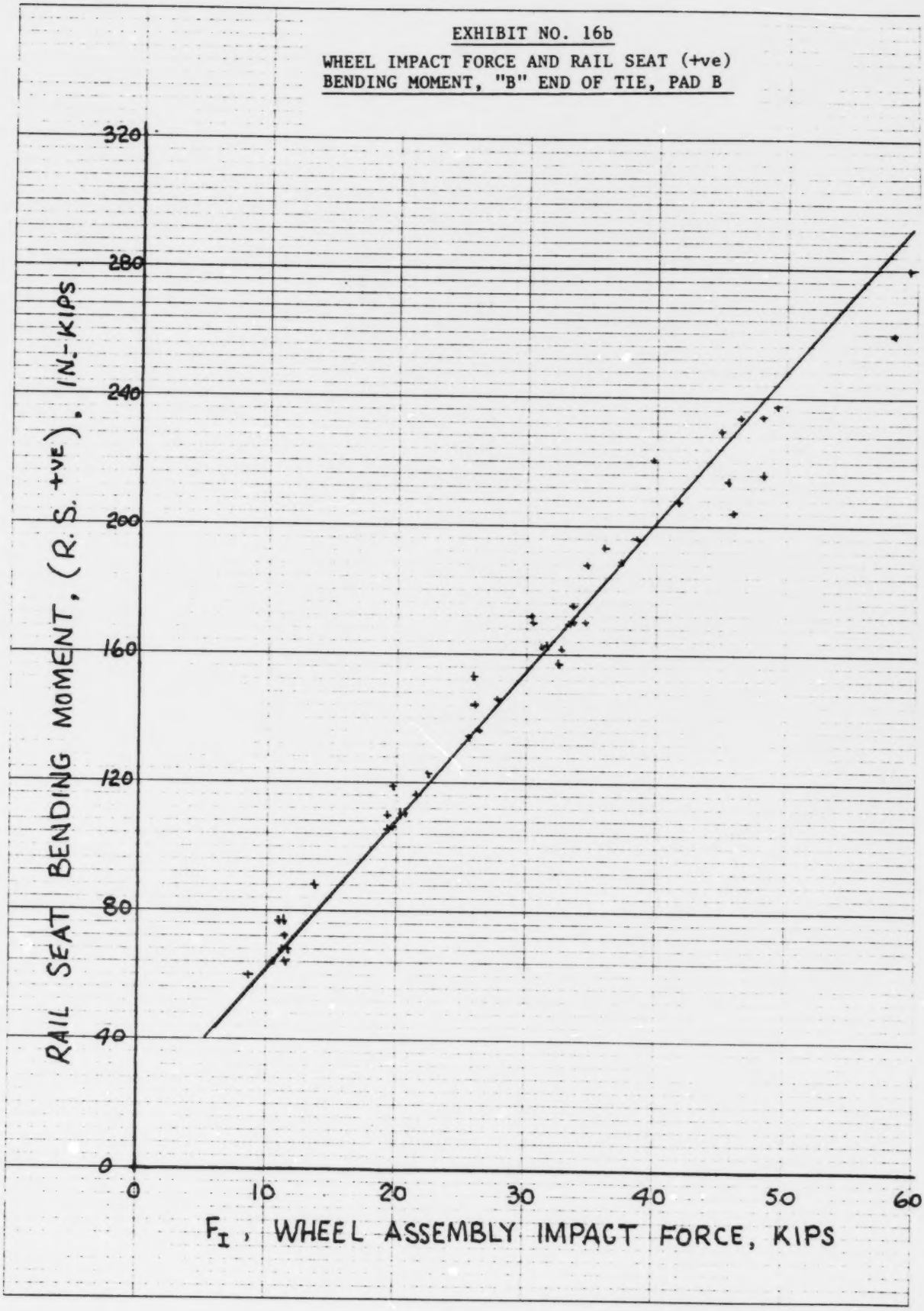
EXHIBIT NO. 16b

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "B" END OF TIE, PAD B

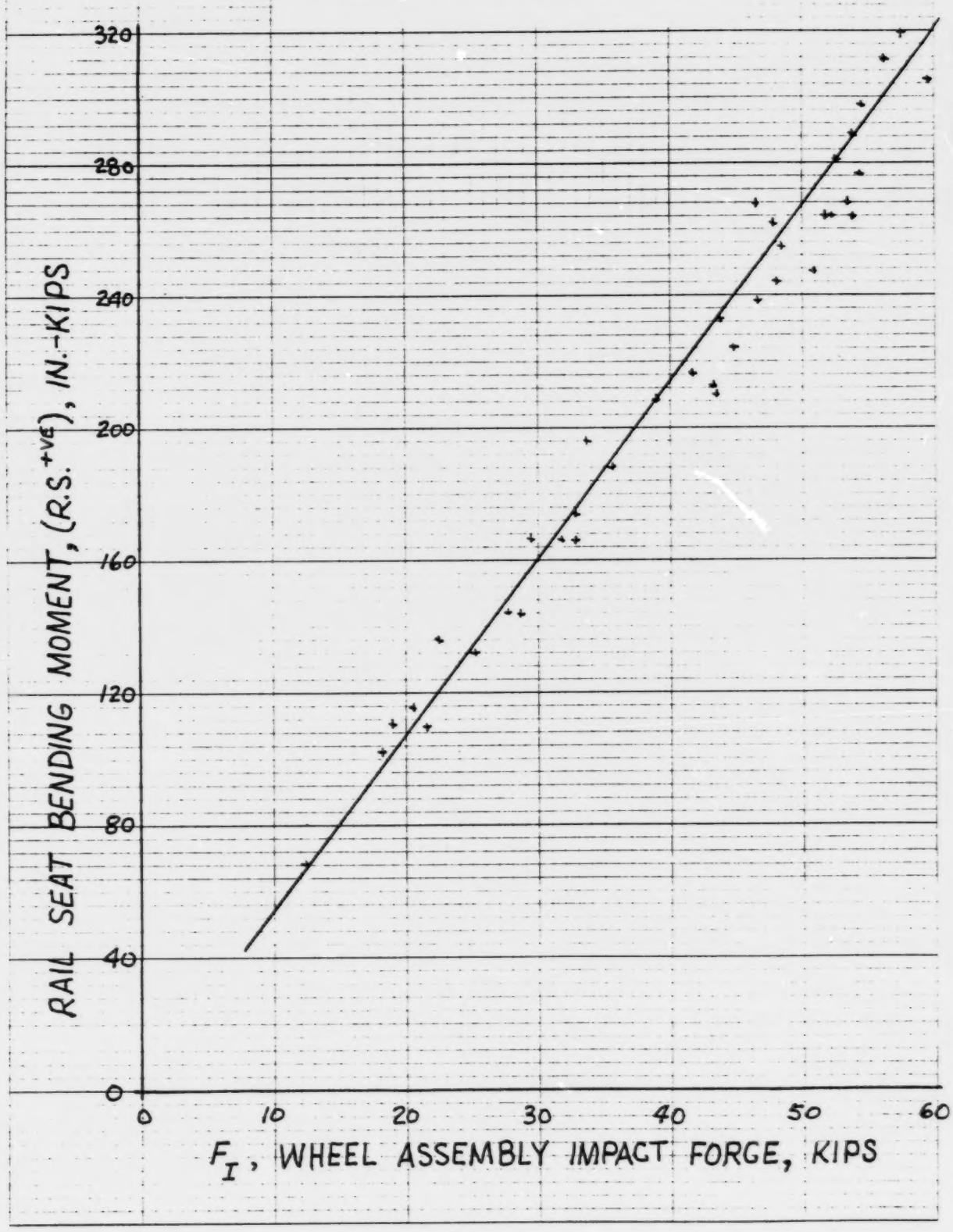


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 16c

WHEEL IMPACT FORCE AND RAIL SEAT (+ve)
BENDING MOMENT, "B" END OF TIE, PAD C



46 0700

10 X 10 TO THE INCH
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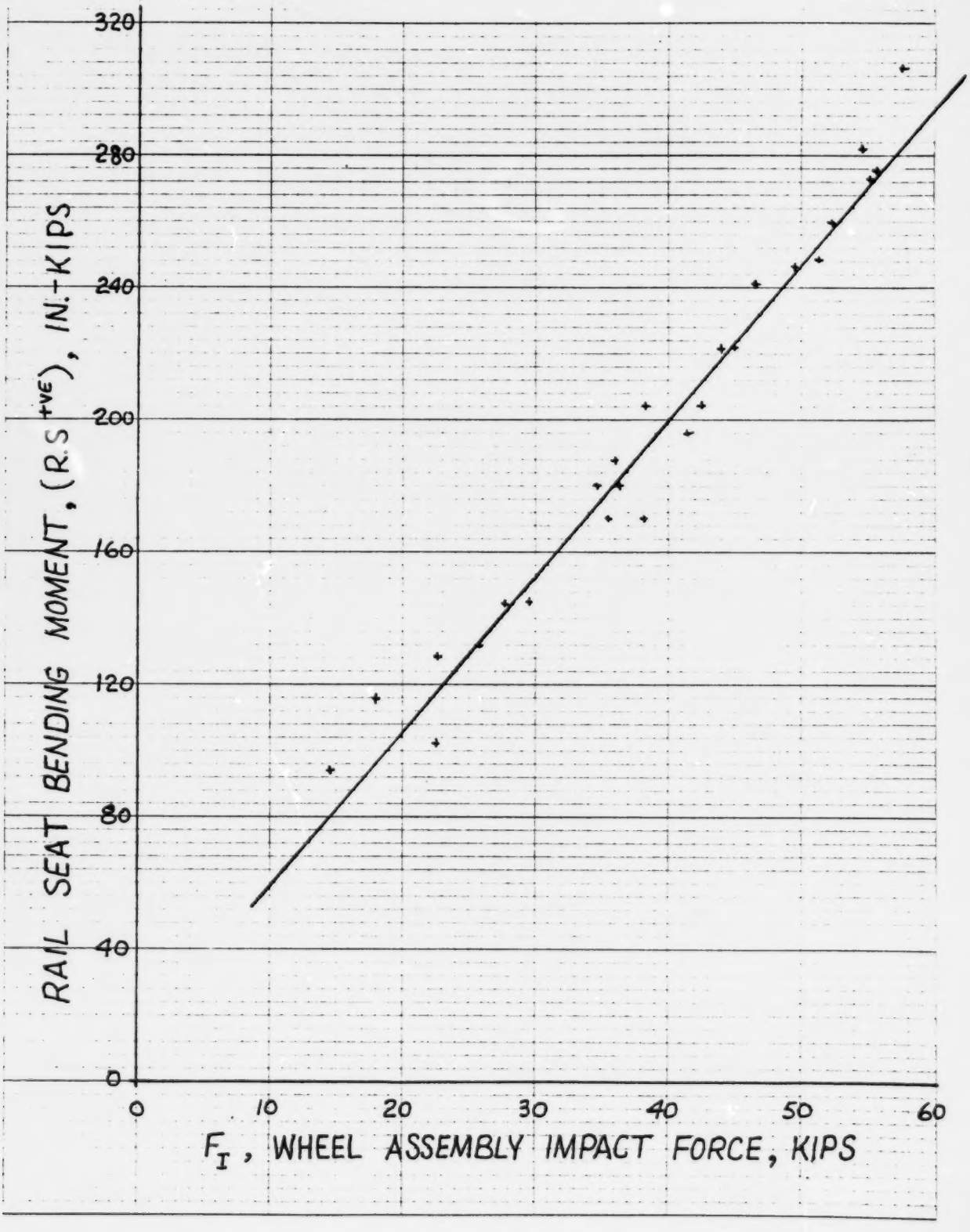
EXHIBIT NO. 16d

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "B" END OF TIE, PAD D



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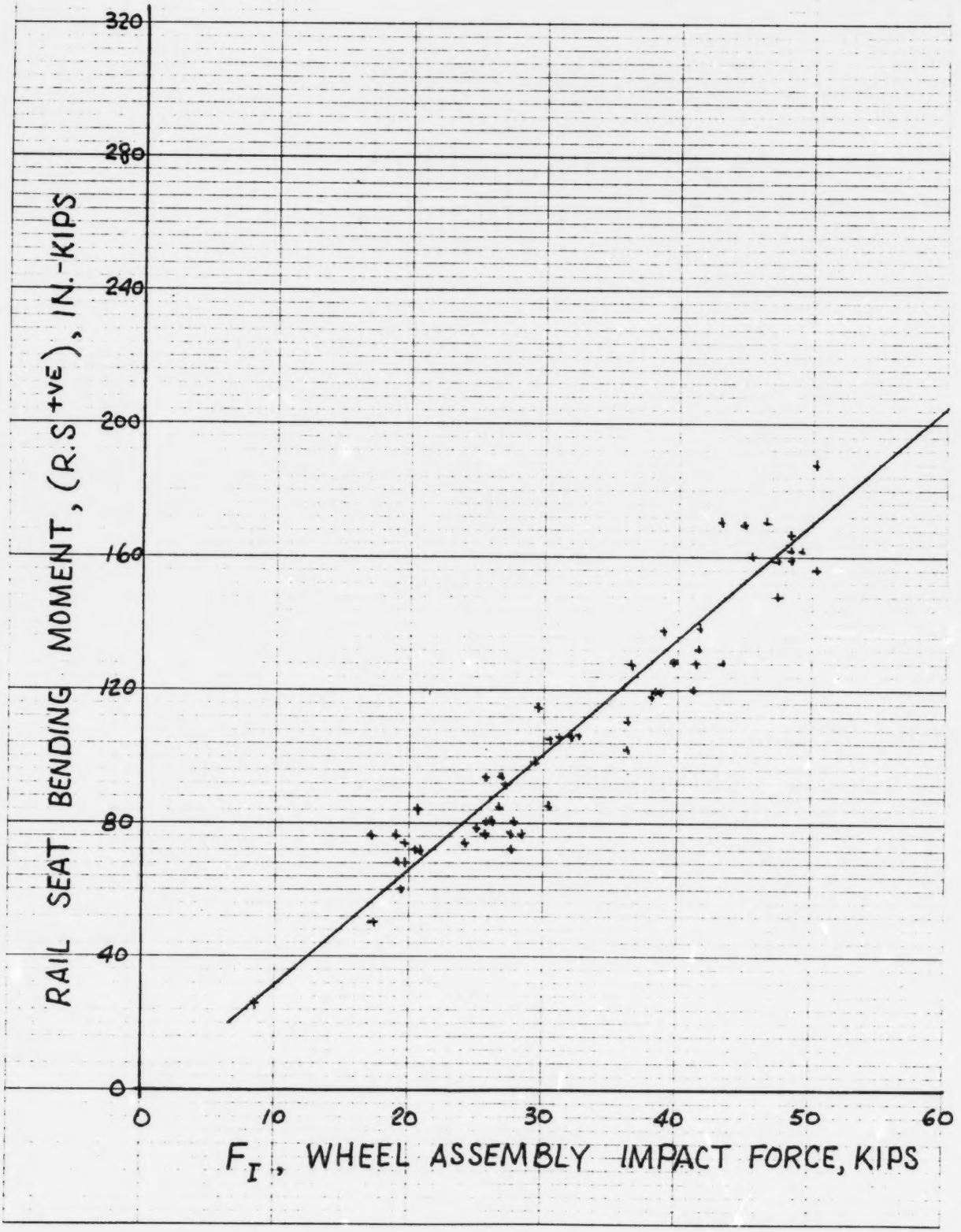
WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "B" END OF TIE, PAD E



46 0700

10 X 10 TO THE INCH
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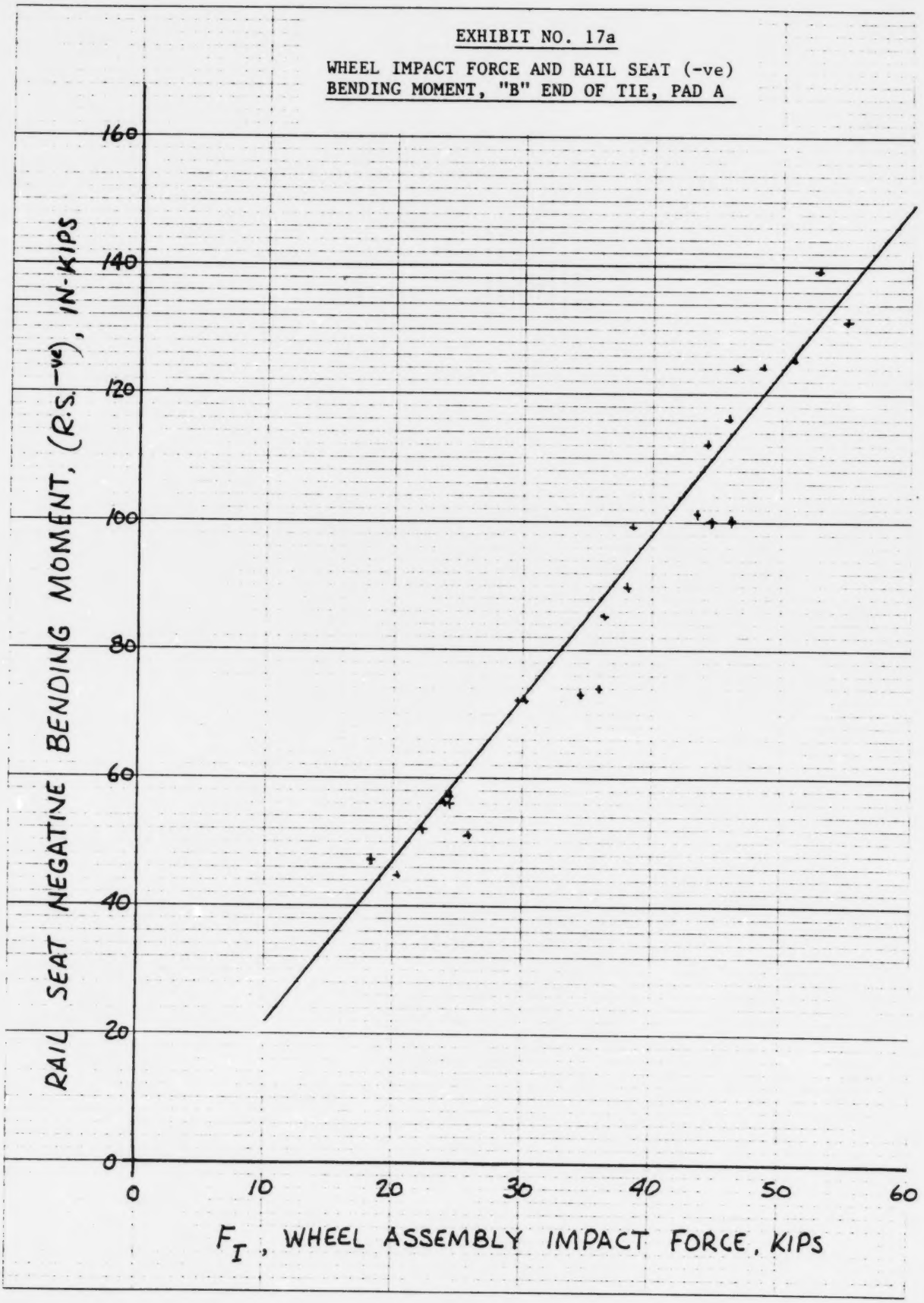
EXHIBIT NO. 17a

WHEEL IMPACT FORCE AND RAIL SEAT (-ve) BENDING MOMENT, "B" END OF TIE, PAD A

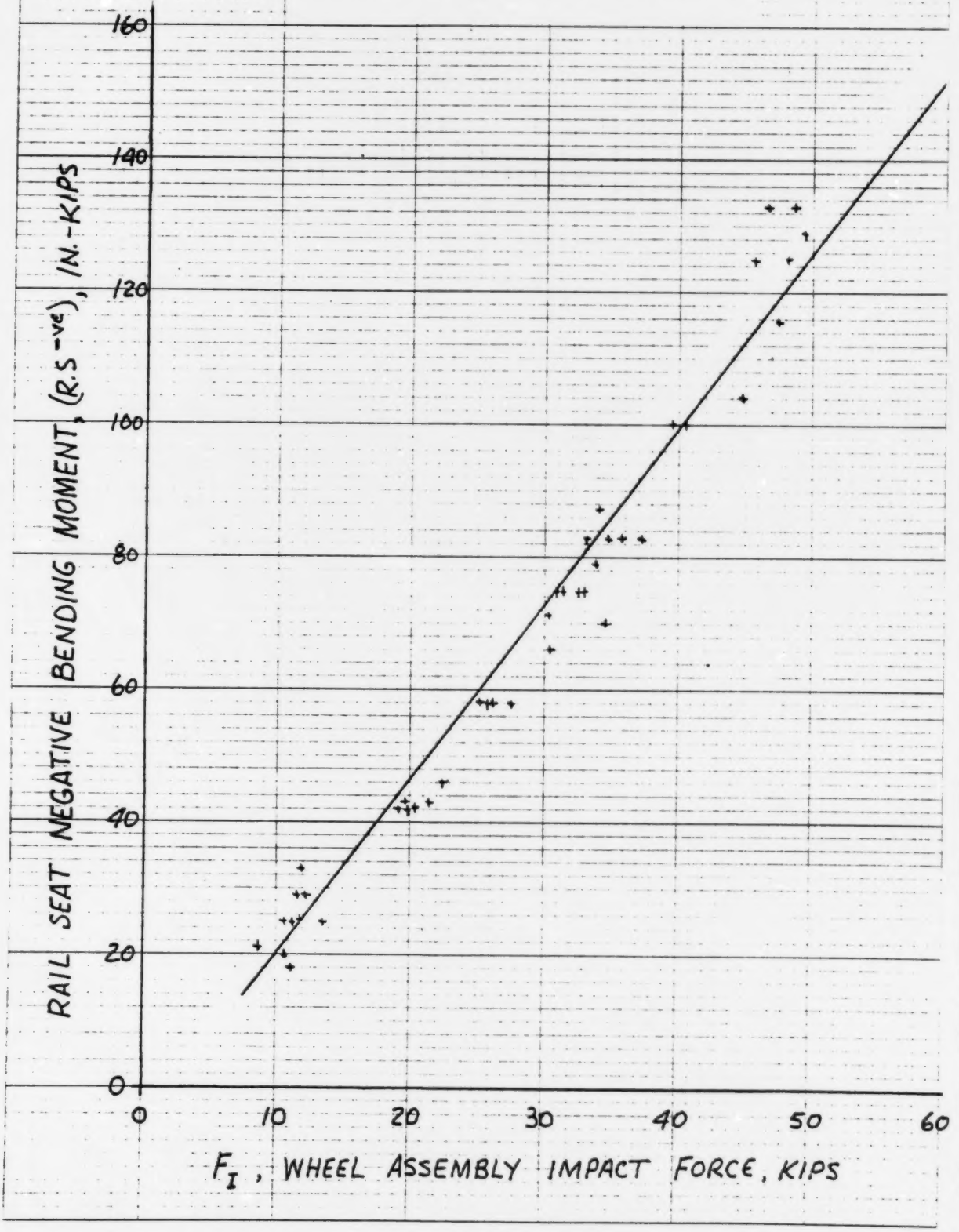


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 17b

WHEEL IMPACT FORCE AND RAIL SEAT (-ve) BENDING MOMENT, "B" END OF TIE, PAD B

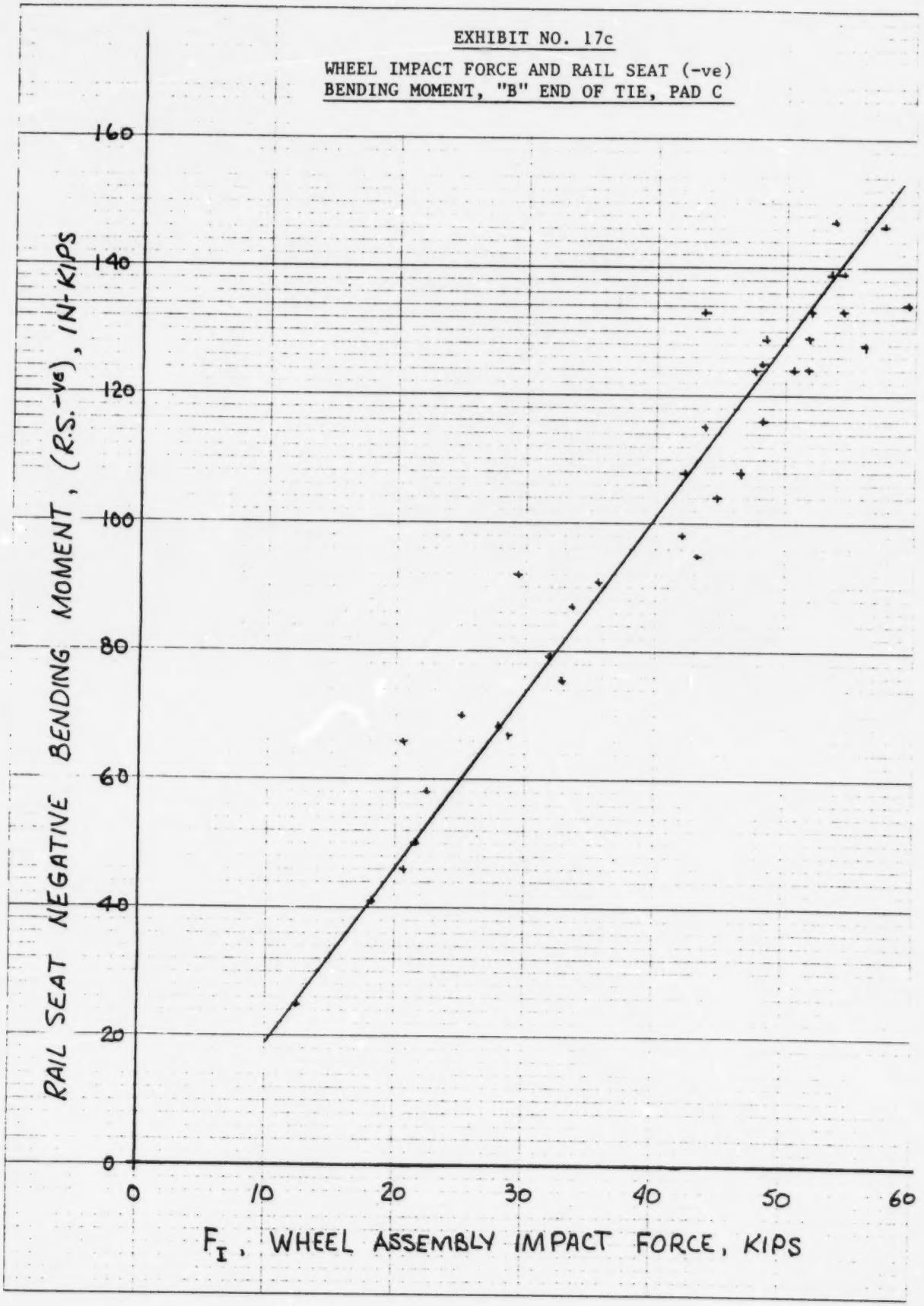


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 17c

WHEEL IMPACT FORCE AND RAIL SEAT (-ve)
BENDING MOMENT, "B" END OF TIE, PAD C

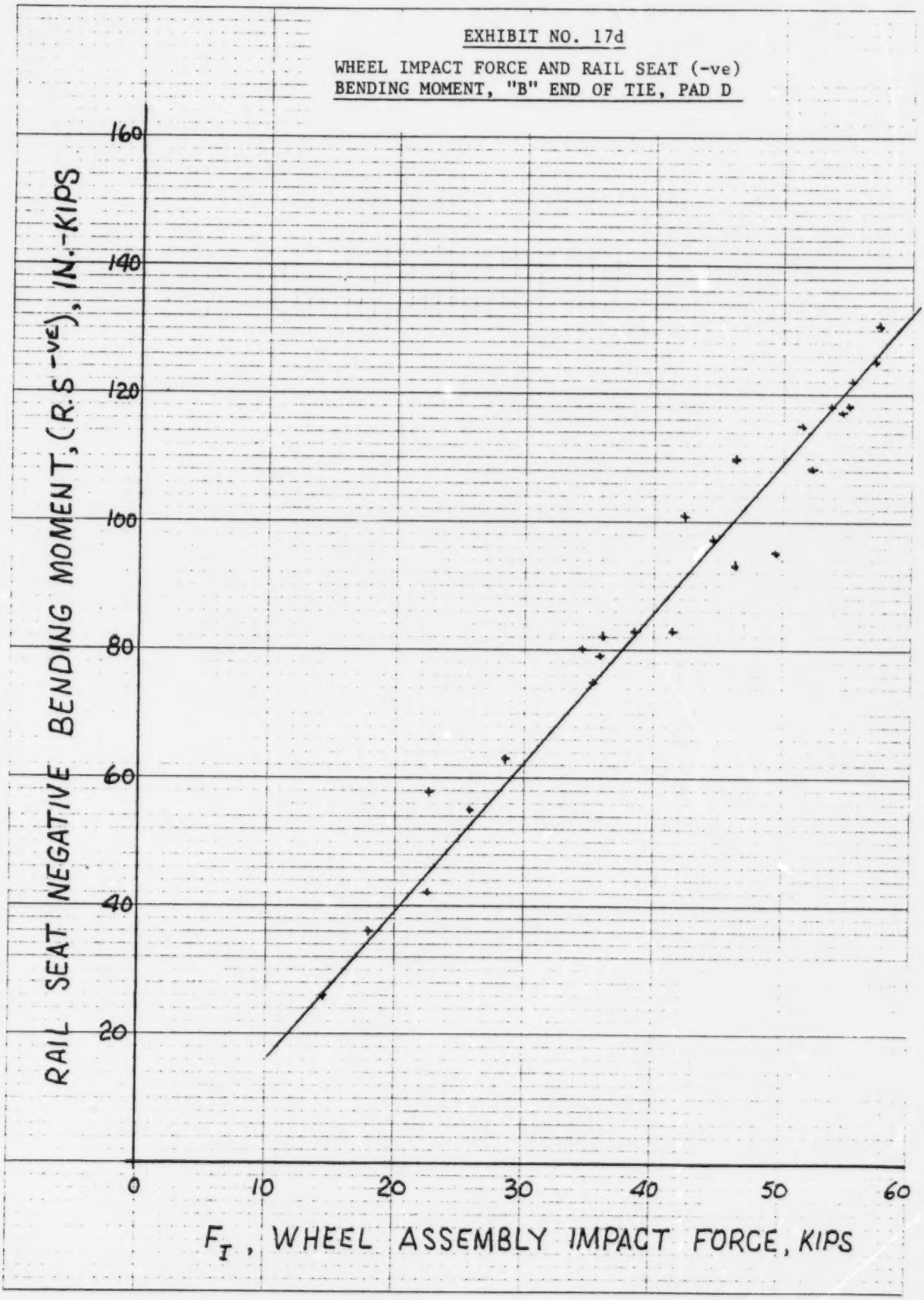


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 17d

WHEEL IMPACT FORCE AND RAIL SEAT (-ve) BENDING MOMENT, "B" END OF TIE, PAD D

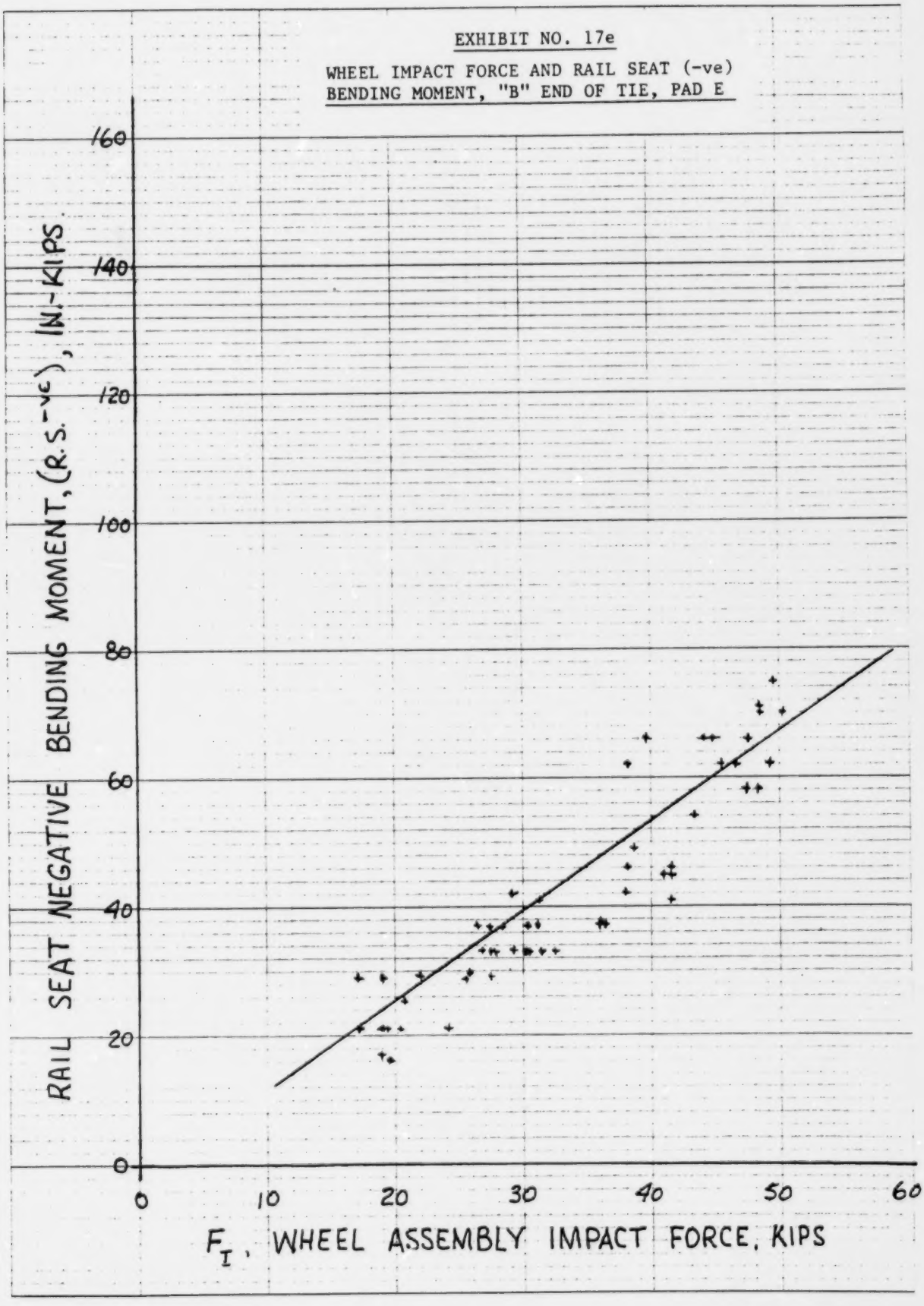


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 17e

WHEEL IMPACT FORCE AND RAIL SEAT (-ve) BENDING MOMENT, "B" END OF TIE, PAD E

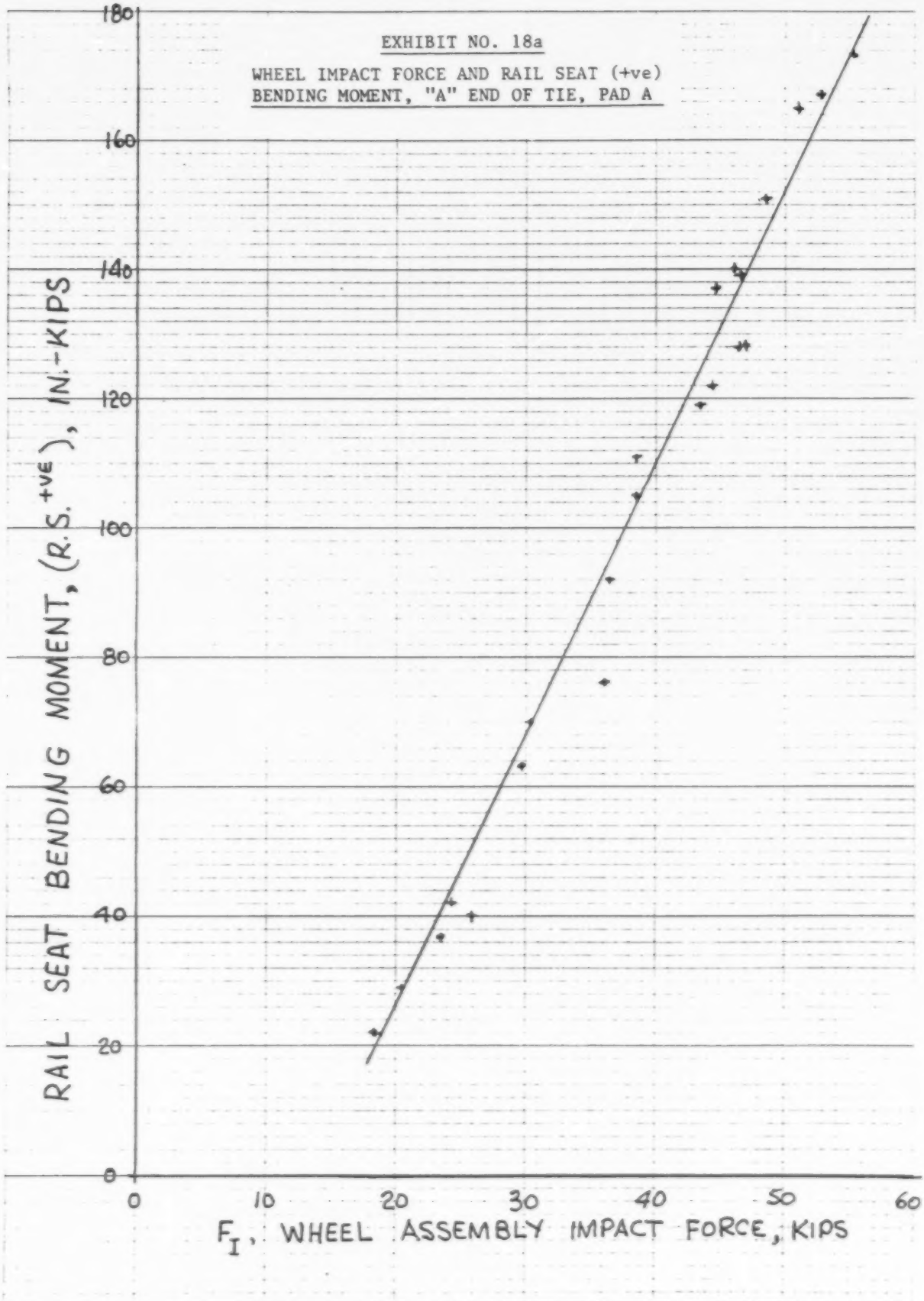


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 18a

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "A" END OF TIE, PAD A



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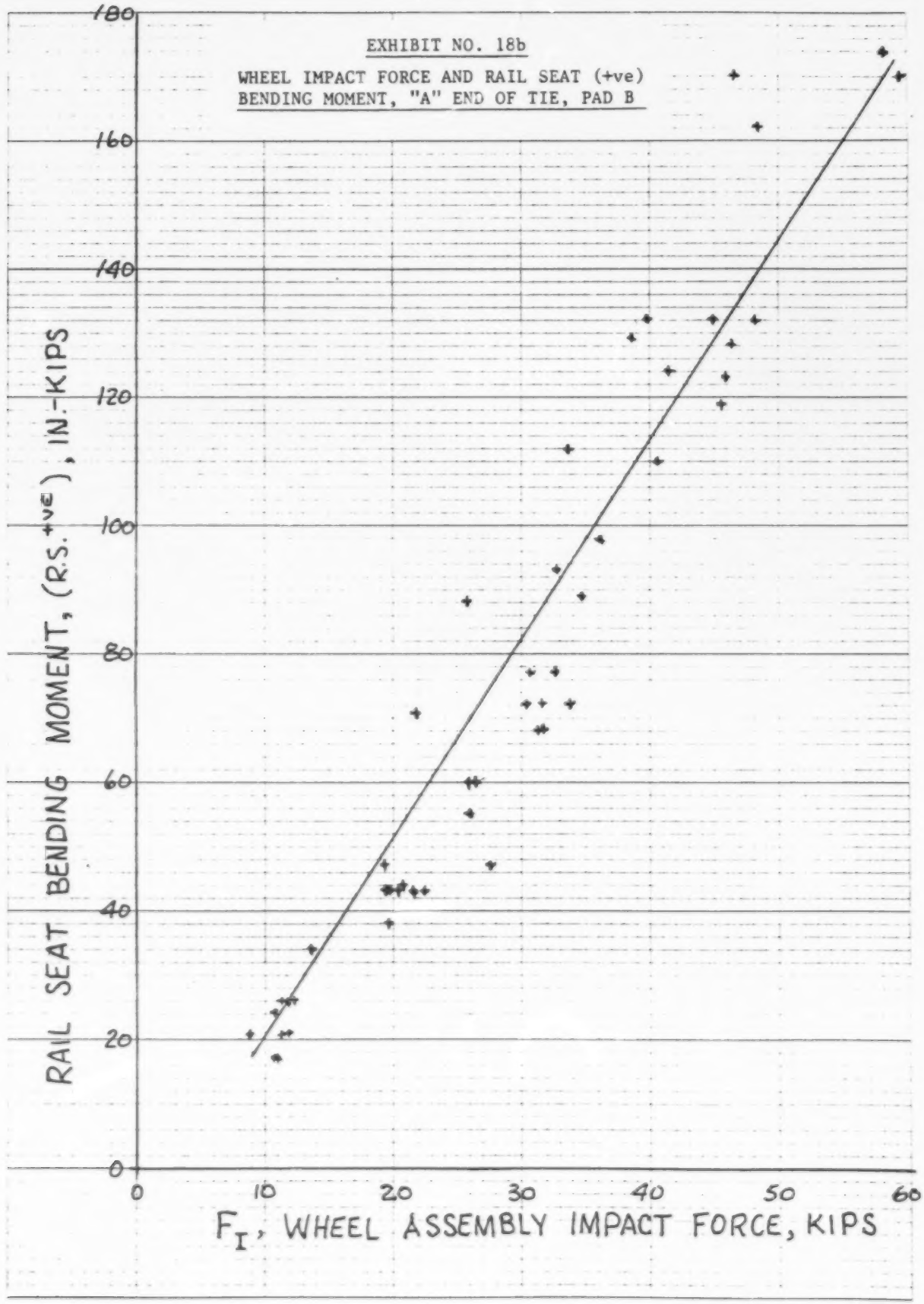
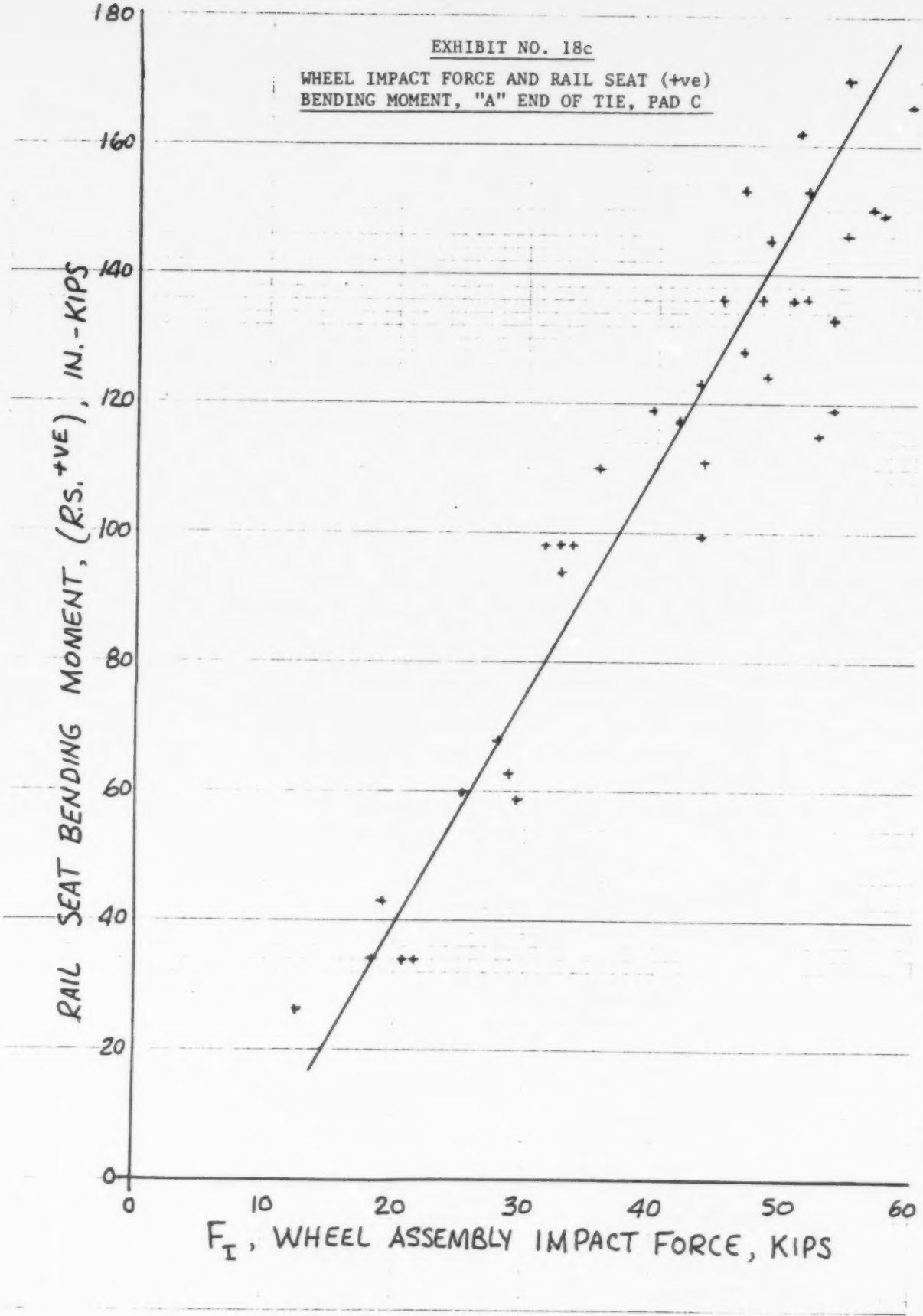


EXHIBIT NO. 18b
WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "A" END OF TIE, PAD B
RAIL SEAT BENDING MOMENT, (R.S.+ve), IN.-KIPS
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
F_I, WHEEL ASSEMBLY IMPACT FORCE, KIPS

46 0700

EXHIBIT NO. 18c

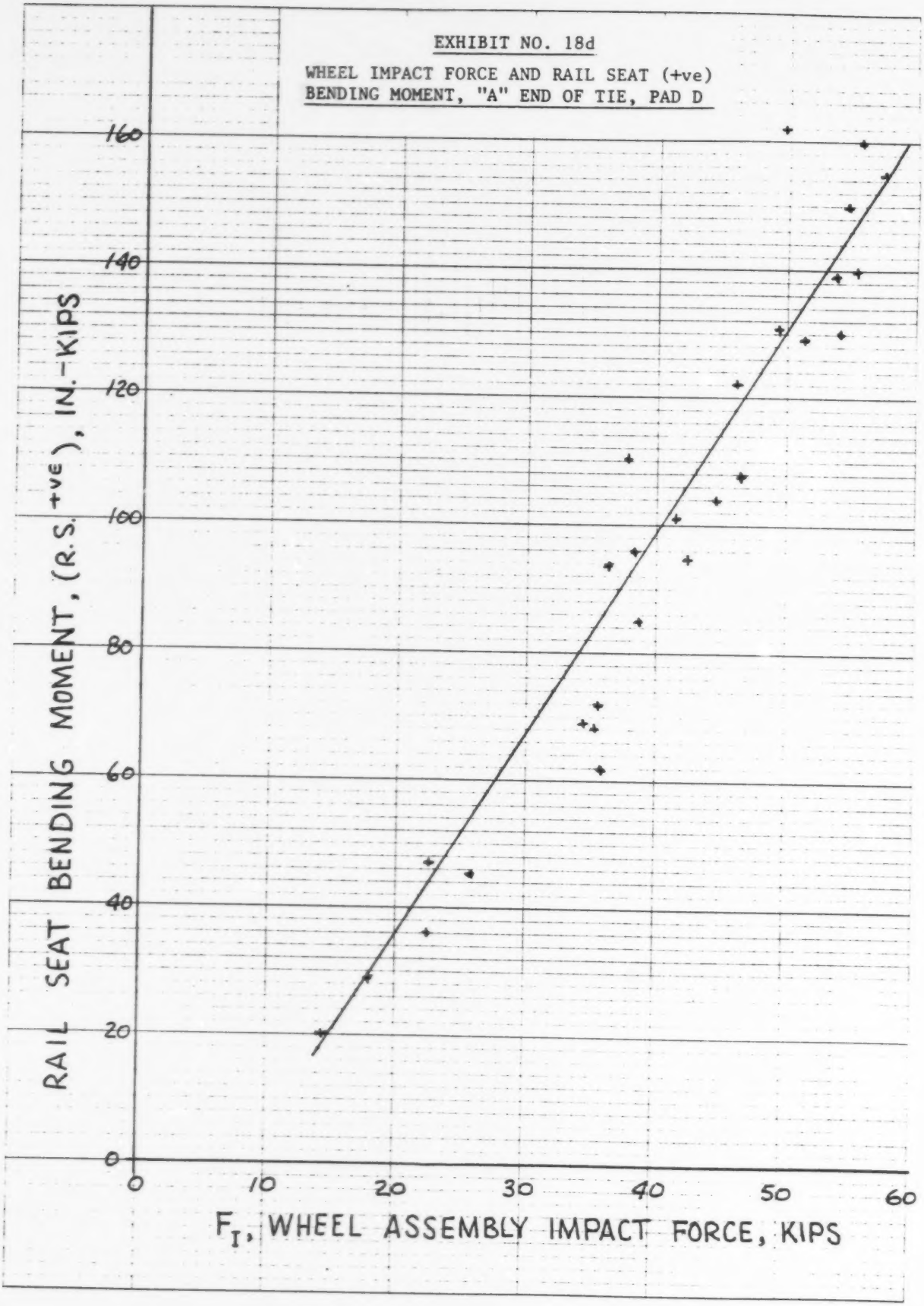
WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "A" END OF TIE, PAD C



46 0700

EXHIBIT NO. 18d

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "A" END OF TIE, PAD D

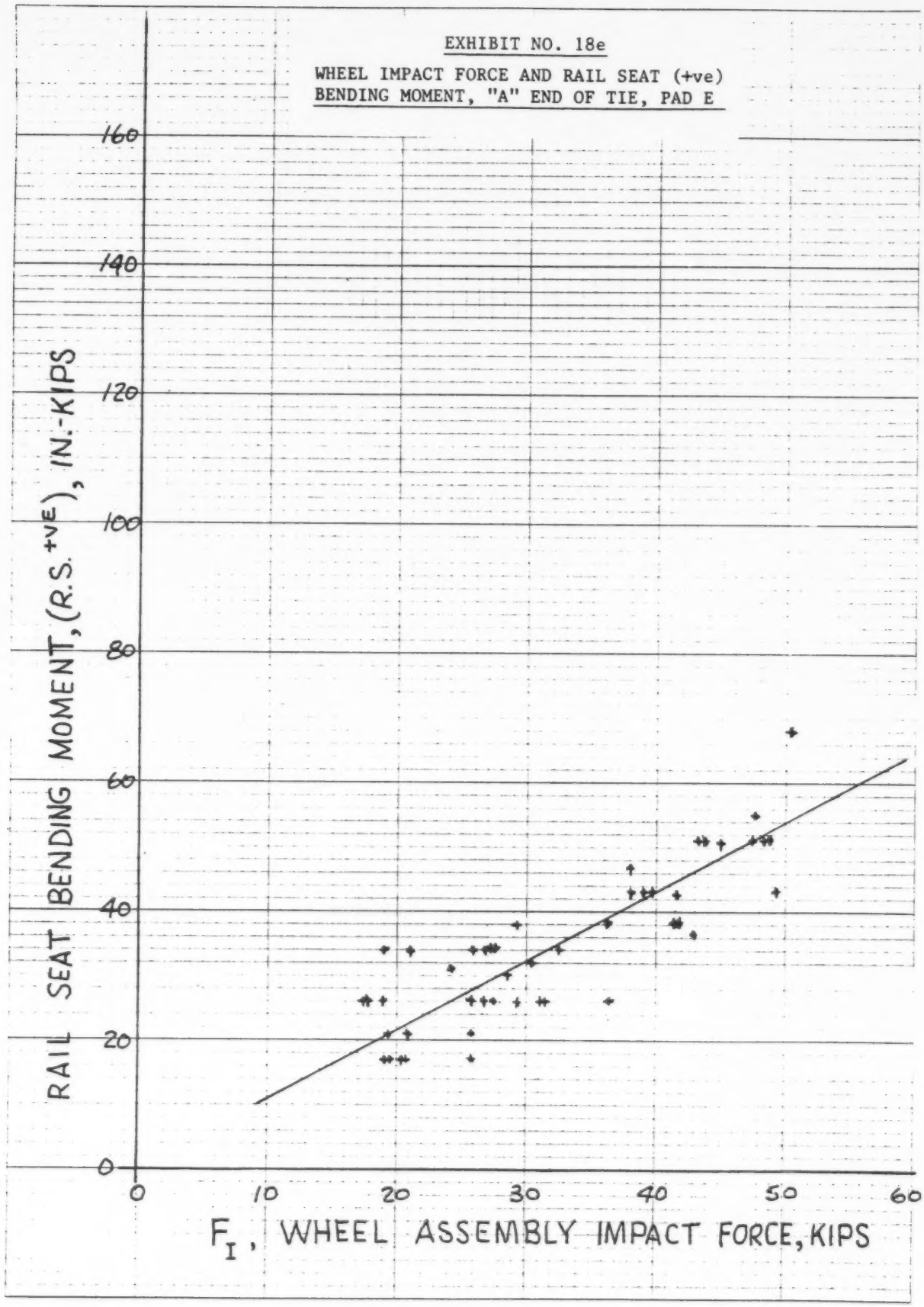


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 18e

WHEEL IMPACT FORCE AND RAIL SEAT (+ve) BENDING MOMENT, "A" END OF TIE, PAD E

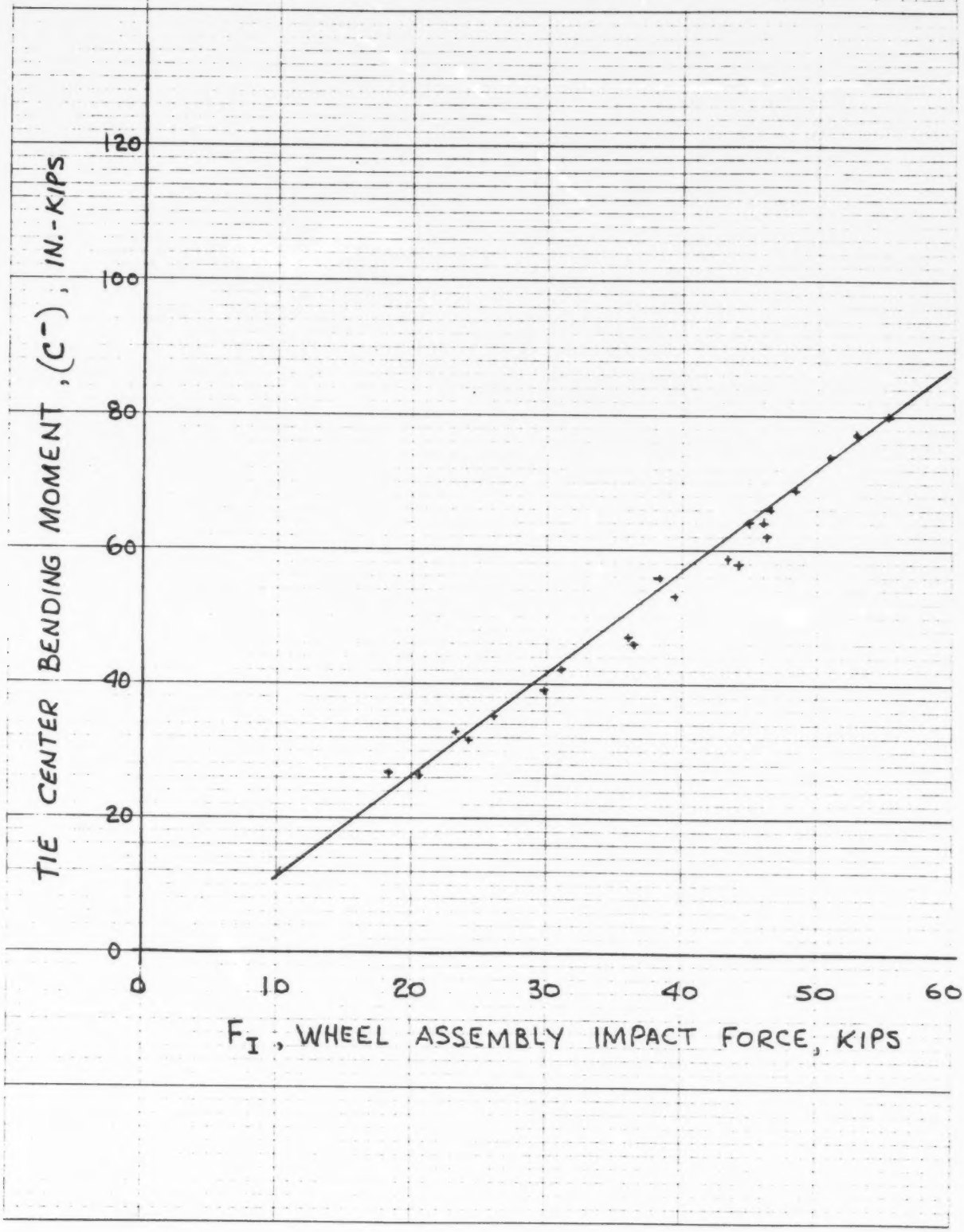


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO

EXHIBIT NO. 19a

WHEEL IMPACT FORCE AND TIE CENTER (-ve) BENDING MOMENT, PAD A

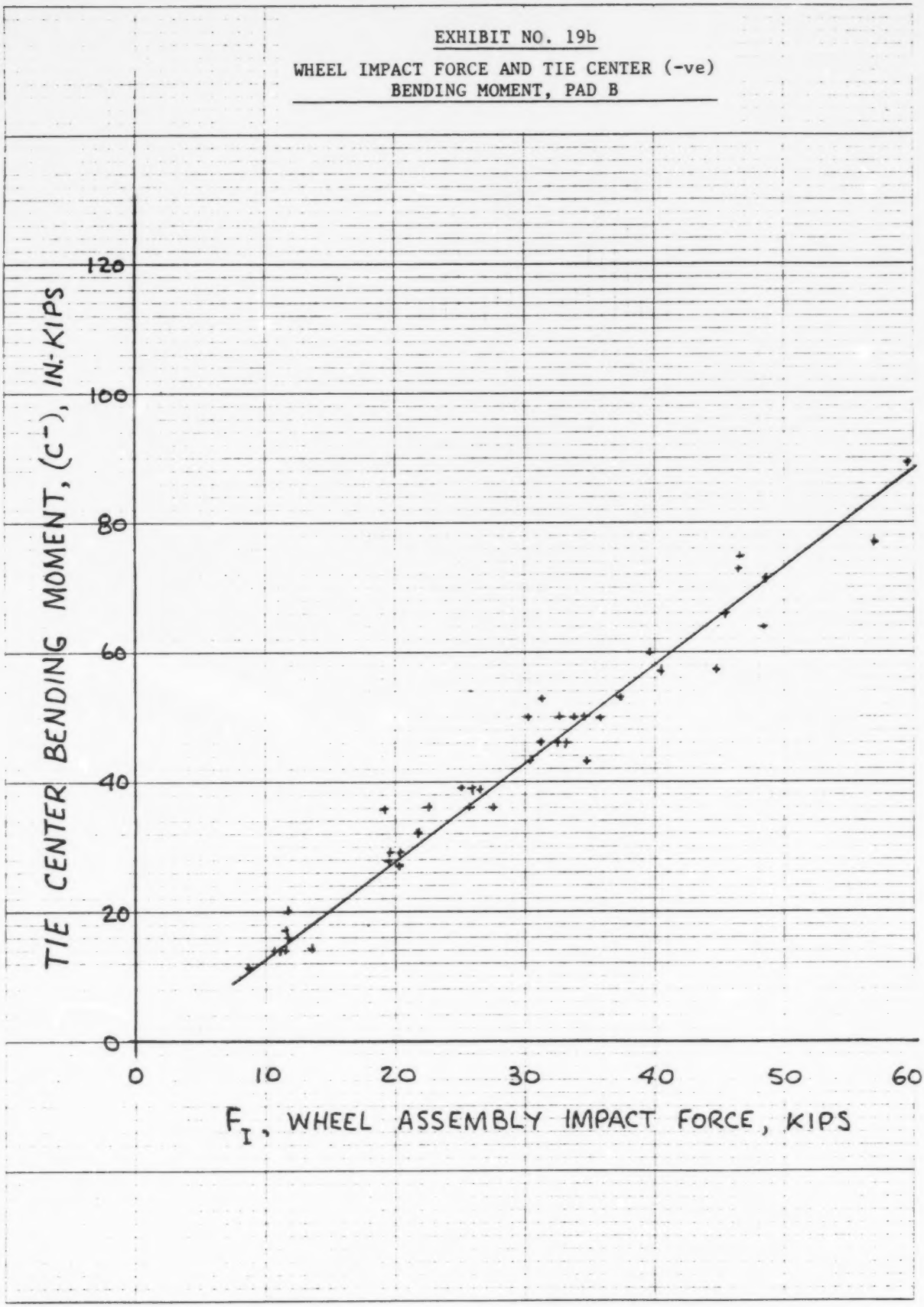


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT NO. 19b

WHEEL IMPACT FORCE AND TIE CENTER (-ve) BENDING MOMENT, PAD B

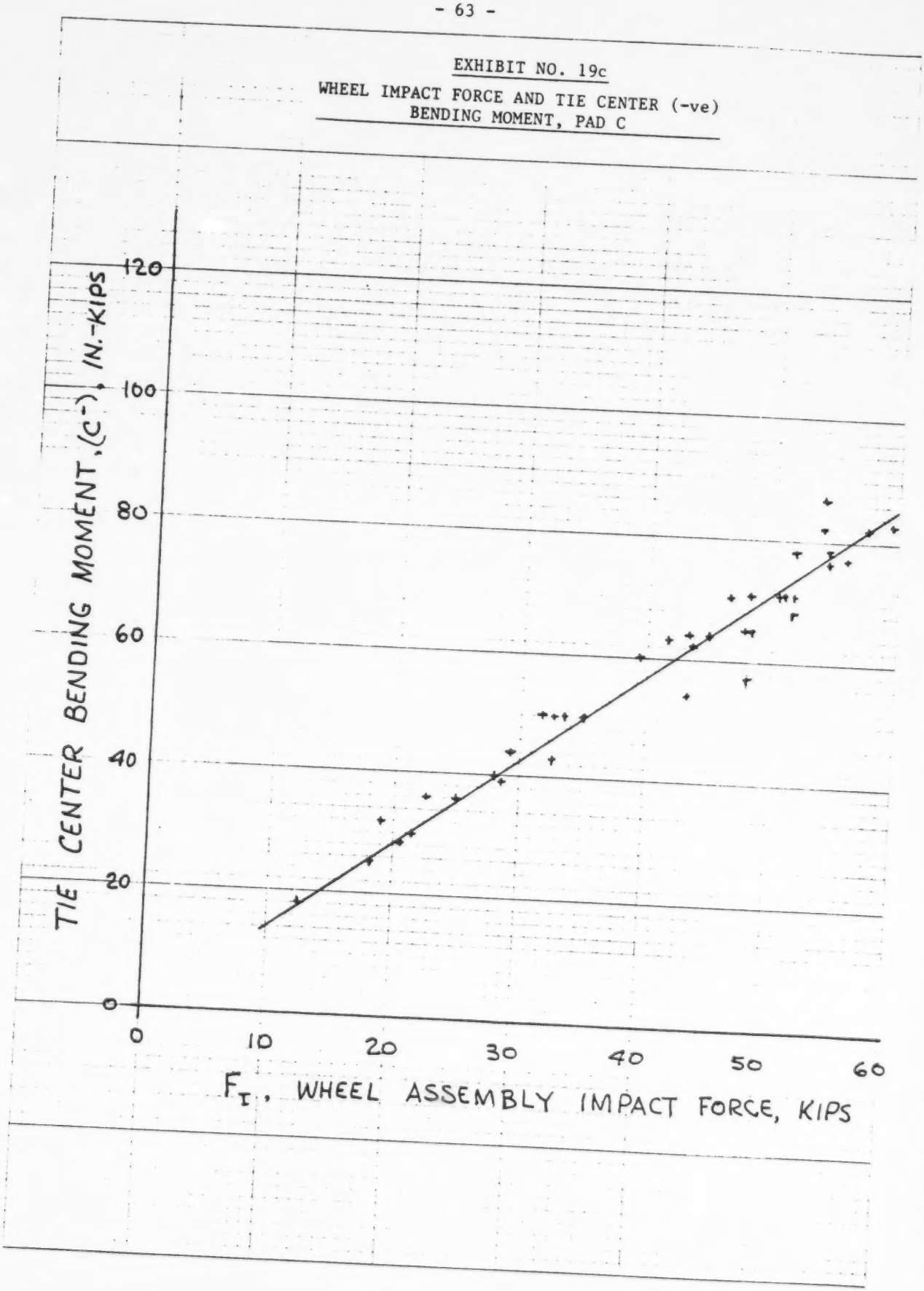


46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

EXHIBIT NO. 19c

WHEEL IMPACT FORCE AND TIE CENTER (-ve) BENDING MOMENT, PAD C



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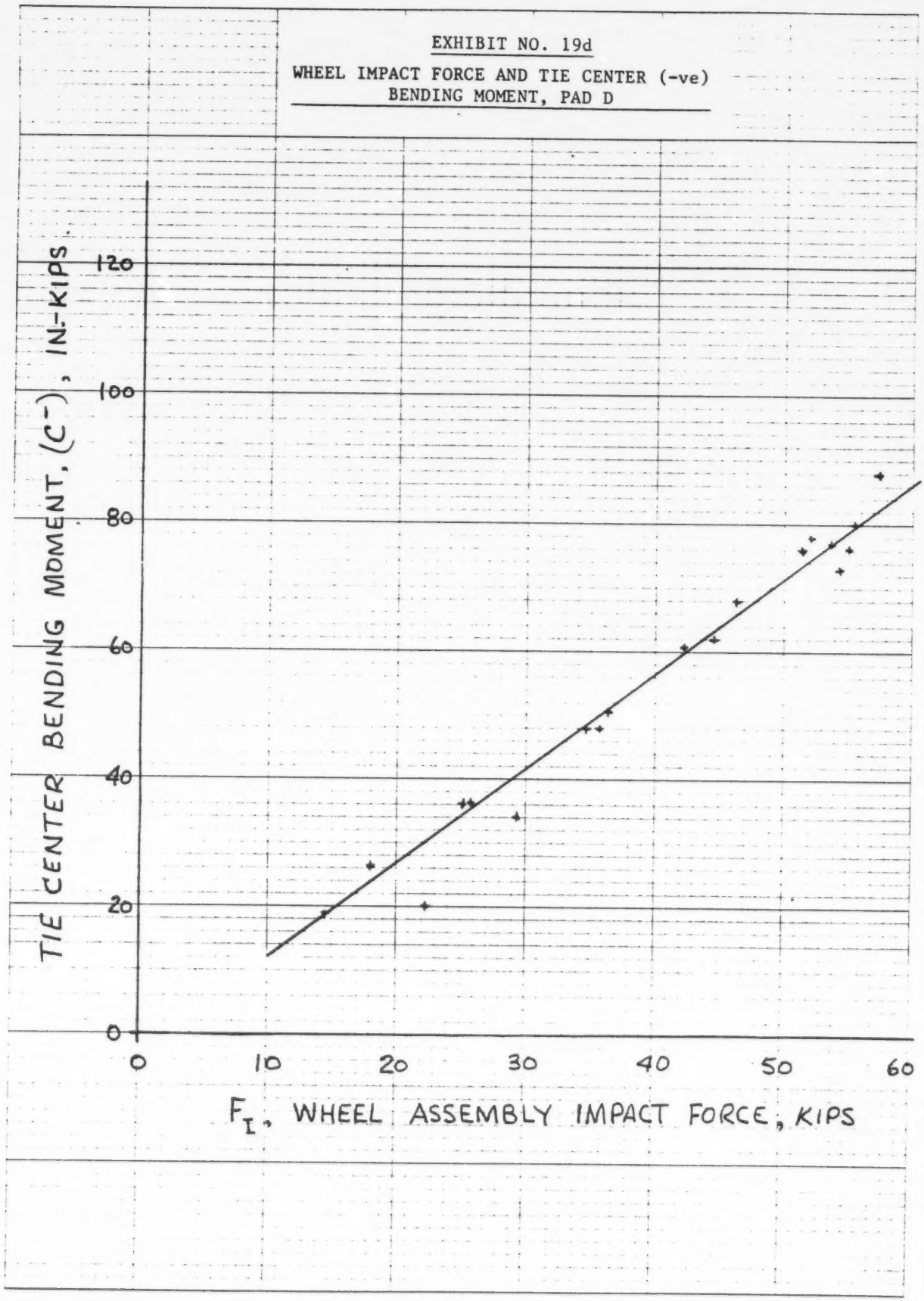
10 X 10 TO THE INCH
KEUFFEL & E

EXHIBIT NO. 19d

WHEEL IMPACT FORCE AND TIE CENTER (-ve) BENDING MOMENT, PAD D

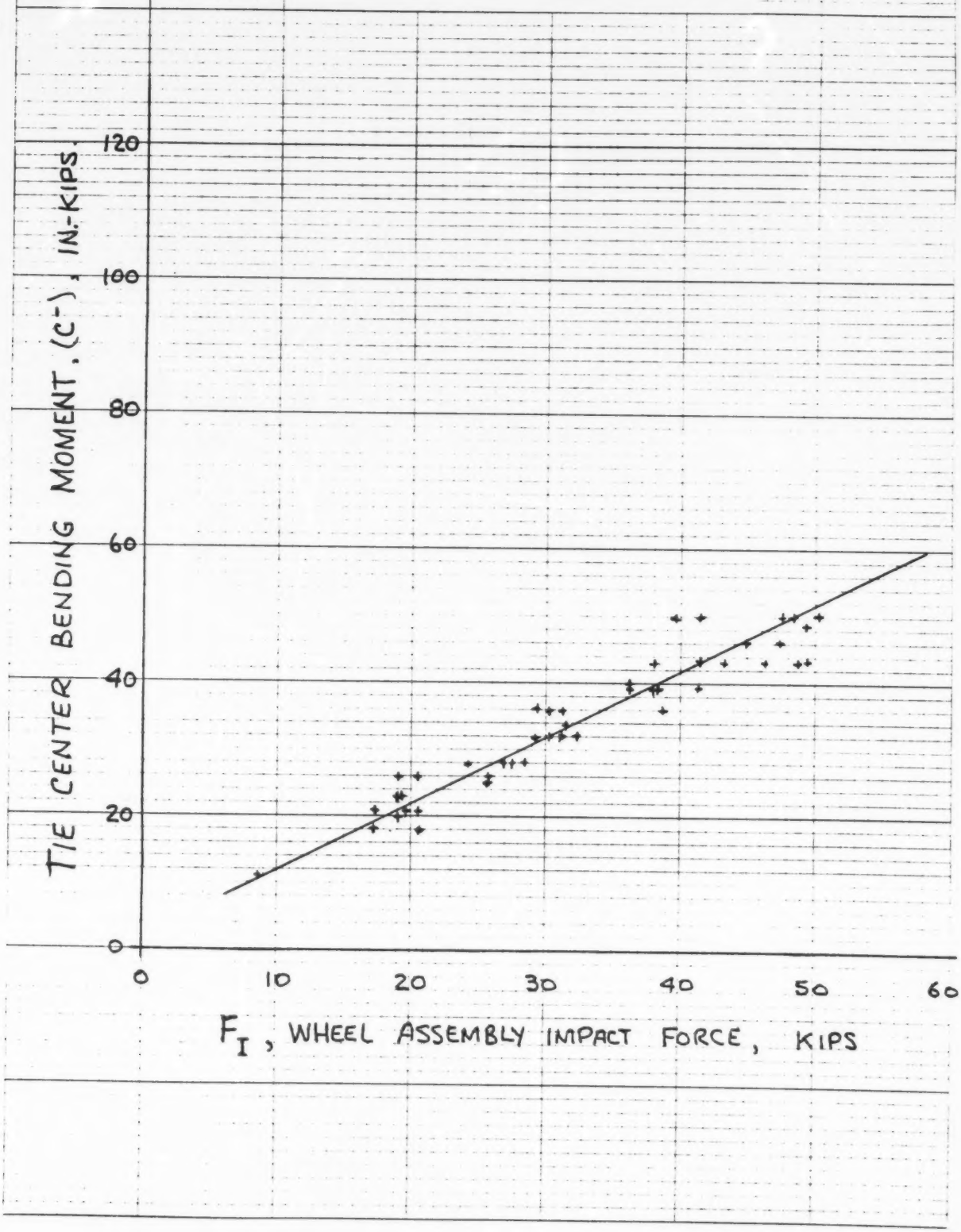


46 0700

10 X 10 TO THE INCH • 7 X 10 PER HALF
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT NO. 19e

WHEEL IMPACT FORCE AND TIE CENTER (-ve) BENDING MOMENT, PAD E



46 0700

10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

APPENDIX B

OUTLINE OF DROP TESTS CONDUCTED SINCE PROJECT INITIATION

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OUTLINE OF DROP TESTS CONDUCTED SINCE PROJECT INITIATION

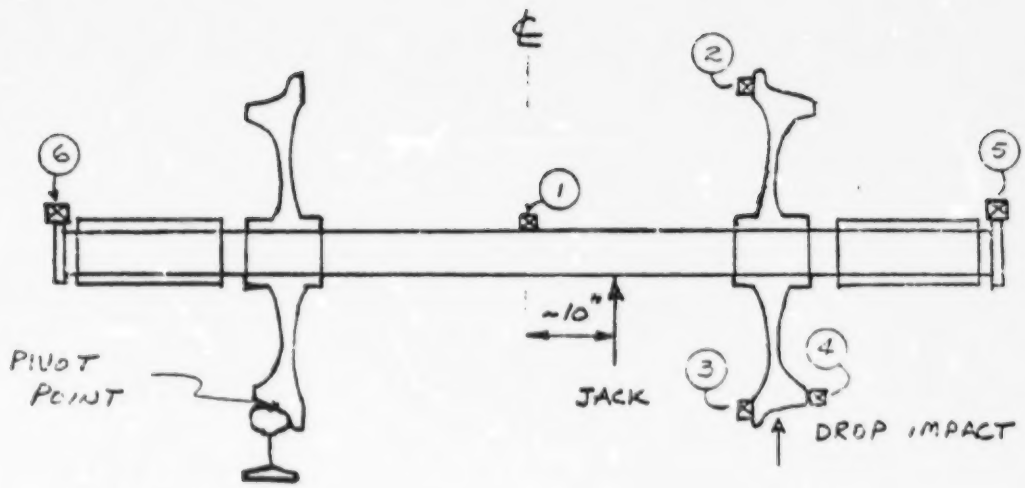
This task was initiated early in February, 1978, with the objective of defining the optimum pad stiffness for use on CN60A concrete ties. It was known at that time that impact loading from vehicles with wheel defects subjected concrete ties in service to rather severe stress fluctuations. The magnitude and frequency of these stresses had not been documented on CN track and questions were raised about the fatigue life of the ties. Alteration of the stiffness of the tie pad offered the most logical possible approach for reduction of tie impact loads.

It was decided to conduct wheelset drop tests in the laboratory and to measure the forces generated at the wheel/rail contact point. Short pieces of rail were set on three concrete ties and one rail only was strain gauged with a shear circuit in order to measure the amount of force that was distributed to the two outer ties. By subtracting this distributed force from the measured impact force, the amount of force that was transmitted directly into the tie rail seat under the dropped wheel could be obtained. The laboratory test set-up is shown in Exhibit No. 20. It is to be noted that one end only of the wheelset was dropped while the opposite wheel/rail contact point remained as a pivot. Prior to commencing tests on pad evaluation, the force measurement system had to be calibrated, and this turned out to be a major problem. While it is not normal to present negative test results, the author feels that a description of these problems would aid future researchers in avoiding instrumentation pitfalls.

EXHIBIT NO. 20

WHEELSET DROP TESTS
ACCELEROMETER PLACEMENT ON WHEELSET

36" DIA. WHEELS, 6-1/2" x 12" JOURNAL BEARINGS



February 9, 1978 - As shown in Exhibit No. 20, six Bell and Howell Type 4-281-0001 piezoelectric accelerometers were mounted on small aluminum blocks which were in turn epoxied to the wheelset at various locations. All axes of accelerometers were vertical. These accelerometers had a dynamic range up to 100 g, shock limit to 500 g (1 millisecond duration), and a flat frequency response from 4 Hz to 10,000 Hz. The unfiltered accelerations were fed into an analog computer, combined into an equation for force calculation, and were then displayed on strip chart. It was quickly determined that the chart recorder did not have sufficient frequency response. This was readily overcome by recording the data on a digital storage oscilloscope and playing back at reduced speed on chart.

To calibrate the system, the pads were removed from the central tie leaving the rail supported only by the two outboard ties. The calculated impact force (from accelerometers) could then be compared directly to measured force in the rail (from the rail shear circuit). It was found that the two forces tended to vary and a consistent calibration curve could not be obtained.

February 22, 1978 - The unfiltered accelerometer signals showed accelerations in excess of 50 g and frequencies in the neighbourhood of 2.5 kHz. The forces calculated from the accelerometers showed many high frequency peaks superimposed on the primary impact force, and it was felt that if these peaks could be filtered off, then possibly a consistent calibration curve could be obtained. There ensued many tests with various levels of signal filtering. Single stage filters with roll-off frequencies ranging from 10 to 100 Hz were tried, and while the force signal was "cleaned up", a consistent calibration curve could still not be obtained.

March 8, 1978 - Filters were then cascaded at 2, 3 and 4 levels with roll-off frequencies between 200 and 500 Hz. The force calibration curve was still inconsistent. It should be noted that no filters were used on the rail shear circuit as it was relatively clean to begin with and gave repeatable results throughout the course of the tests. While the problems associated with filtering the accelerometer signals continued, it was determined that the wheelset axle had a fundamental frequency of 100 Hz and the rail had a fundamental frequency of 195 Hz.

March 17, 1978 - At about this time, the equations used to solve for impact force from accelerations were reviewed, and it was determined that a lateral acceleration should have been included. The equations were rewritten, this time to utilize the vertical accelerations from each end of the axle and one lateral acceleration at axle level. Equations are given in Exhibit No. 21. There followed another round of tests with various third-order Butterworth filters, and, while the results were often tantalizing, consistent calibration remained elusive. It was found that inclusion of the lateral acceleration increased the calculated impact force from 7 to 12%. Virtually all of the calculated force levels were within ± 20% of the directly measured rail force, but it was felt this level of accuracy was insufficient for comparative appraisal of concrete tie pads.

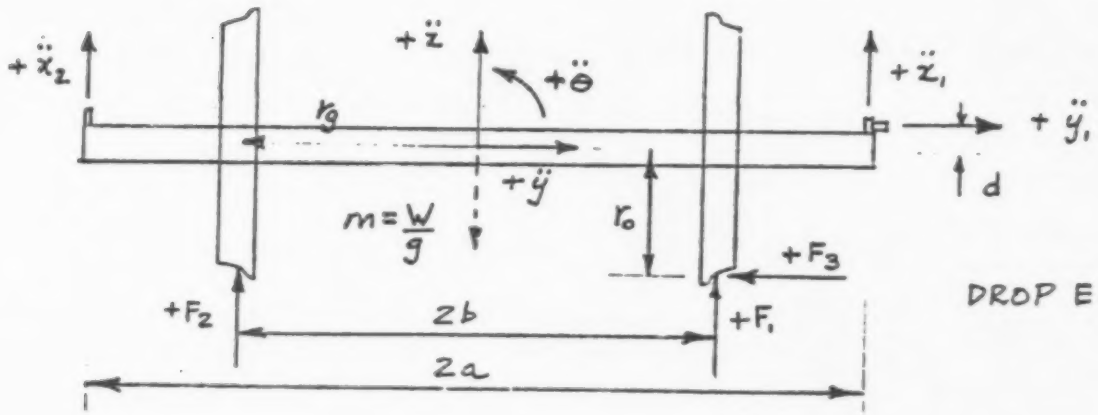
One other factor emerged - depending on the level of filtering, negative forces were sometimes calculated as the wheel bounced off the rail. This was an impossibility as only gravity worked in the downward direction. At about this time it was decided that piezoelectric accelerometers could not be utilized to obtain consistent impact force measurements.

April 5, 1978 - On this date it was decided to use Statham strain gauge accelerometers and new sets of aluminum blocks were fabricated. These accelerometers had an acceleration range of ± 25 g, natural frequency of roughly 430 Hz, and static overload capacity of ± 75 g. There was concern that the accelerometers might suffer damage from the repeated pounding but they performed well and maintained their calibrations. They were used for several series of tests.

April 7, 1978 - A series of drops were conducted with both the rail shear force and the calculated impact force (from accelerations) filtered at 241 Hz roll-off with third-order Butterworth filters. It was found that the two force levels agreed within ± 5% for impact forces up to 25 kips. Beyond that level, the scatter increased. It was felt that impact force levels of 25 kips were sufficient for pad evaluation and it was decided to get on with the testing program. To this point, all the testing had been conducted in the laboratory. The hard concrete floor did not bear any resemblance to actual roadbed and the incessant pounding was an aggravation to personnel in adjacent work areas. It was decided to relocate the testing to the outdoor Track Structures Test Facility adjacent to the Research Centre.

EXHIBIT NO. 21

DETERMINATION OF WHEEL/RAIL IMPACT FORCES
MAR. 17/78



$$F_1 + F_2 = m\ddot{x} = m\left(\frac{\ddot{x}_1 + \ddot{x}_2}{2}\right)$$

$M_{cg}=0$ $\quad F_1 - F_2 - F_3\left(\frac{r_o}{b}\right) = m\frac{r_g^2}{b}\ddot{\theta}$ $\qquad \ddot{\theta} = \left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right)$

$$F_1 - F_2 - F_3\left(\frac{r_o}{b}\right) = m\frac{r_g^2}{b}\left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right)$$

$$F_3 = -m\ddot{y} \qquad +\ddot{y}_1 = +\ddot{y} - d\ddot{\theta} = +\ddot{y} - d\left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right)$$

$$= -m\left[\ddot{y}_1 + d\left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right)\right]$$

$$F_1 + F_2 = m\left(\frac{\ddot{x}_1 + \ddot{x}_2}{2}\right)$$

$$F_1 - F_2 = m\left[\frac{r_g^2}{b}\left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right) - \frac{r_o}{b}\left\{\ddot{y}_1 + d\left(\frac{\ddot{x}_1 - \ddot{x}_2}{2a}\right)\right\}\right]$$

$$F_1 = \frac{m}{2}\left[\ddot{x}_1\left(\frac{1}{2} + \frac{r_g^2}{2ab} - \frac{r_o d}{2ab}\right) + \ddot{x}_2\left(\frac{1}{2} - \frac{r_o^2}{2ab} + \frac{r_o d}{2ab}\right) - \ddot{y}_1\left(\frac{r_o}{b}\right)\right]$$

$$F_2 = \frac{m}{2}\left[\ddot{x}_1\left(\frac{1}{2} - \frac{r_g^2}{2ab} + \frac{r_o d}{2ab}\right) + \ddot{x}_2\left(\frac{1}{2} + \frac{r_g^2}{2ab} - \frac{r_o d}{2ab}\right) + \ddot{y}_1\left(\frac{r_o}{b}\right)\right]$$

$$F_3 = \frac{m}{2}\left[-\ddot{x}_1\left(\frac{d}{a}\right) + \ddot{x}_2\left(\frac{d}{a}\right) - \ddot{y}_1(2)\right]$$

July, 1978 - During July, the test track rail shear circuits, which had been installed 2 years previously, were recalibrated in readiness for testing.

September 7 & 8, 1978 - The first comprehensive system calibration tests were conducted on the test track. Correlation of forces was generally within ± 5% up to force levels of 25 kips, above that level the scatter expanded considerably. A rubber pad was inserted on the central tie, and the measured wheel impact force F_I was plotted against the rail shear force F_R (total force transmitted to adjacent ties). While one would have expected some reasonable correlation, there was a "shotgun" blast of data points with ± 30% scatter about the mean. The central pad was removed and the system recalibrated. The F_I vs F_R plot showed the forces to correlate on a curve with ± 5% scatter band but F_R/F_I was increasing at the higher force levels. The calibration curve was still unsatisfactory.

September 15, 1978 - The system was recalibrated with the rail force F_R compared against the filtered wheel impact force F_I. Four levels of filtering were used and the average ratio (F_R/F_I) was determined for a series of nominal impact forces ranging from 12 to 30 kips.

Filter on F_I	Ratio (F_R/F_I)	
None	1.08	
120 Hz	0.93	No filter on F_R
241 Hz	0.99	
None	1.08	
120 Hz	0.94	F_R filtered at 120 Hz
241 Hz	1.00	

It was clear that the results could be "cooked" according to selection of signal filter. Further, the ratio (F_R/F_I) increased from something in the order of 0.8 at force levels of 12 kips to something around 1.20 at force levels of 30 kipss.

While the calibration curve was still considered unsatisfactory, it was felt that, if the relationships between F_I and F_R held consistent and repeatable, it would still be possible to use the measurement system to evaluate comparative performances of various concrete tie pads.

November 6, 1978 - By this time it was clear that selection of signal filter could seriously alter results. Having become tired of building special filters, some fit programmable binary coded decimal (BCD) 4-pole low-pass filters were purchased having roll-off frequency adjustment within the range 0.5 to 511.5 Hz.

A complete series of calibration tests was run with unfiltered signals and with filter roll-offs of 70, 80 and 100 Hz on both the rail circuit and the accelerometer wheel force circuit. Inconsistencies were still present but it was decided to go ahead with the pad evaluation tests.

November 8,9,10, 1978 - Over the course of three days, roughly 340 drop tests were conducted on 7 different types of concrete tie pads. It was found that in the majority of drops, the measured force in the rail exceeded the calculated wheel impact force, a physical impossibility unless the central tie exerted negative downward force on the rail. Further, the forces fluctuated rather wildly throughout the test series, and it was decided to scrap all the data. Two factors had been determined from the tests. Forces could not be accurately determined from accelerations and the natural roadbed support appeared to be changing as the tests progressed. At this point it was virtually back to square one -- the instrumentation and force measurement technique was not reliable and the natural roadbed environment did not offer a stable reference for comparative pad evaluations.

A sample of inconsistent force measurements is shown in Exhibit No. 22. The wheel rail force crosses the rail shear force curve when in fact it should not.

When it was found that use of accelerometers mounted on the wheelset as a means of measuring impact force resulted in unresolvable calibration difficuties, a wheelset with strain gauge bridge circuits located on the wheel plate was adopted as the instrument for measuring the impact force of wheel striking rail. Two-wire D.C. strain gauge transmitter and receiver equipment was used for signal conditioning and amplification.

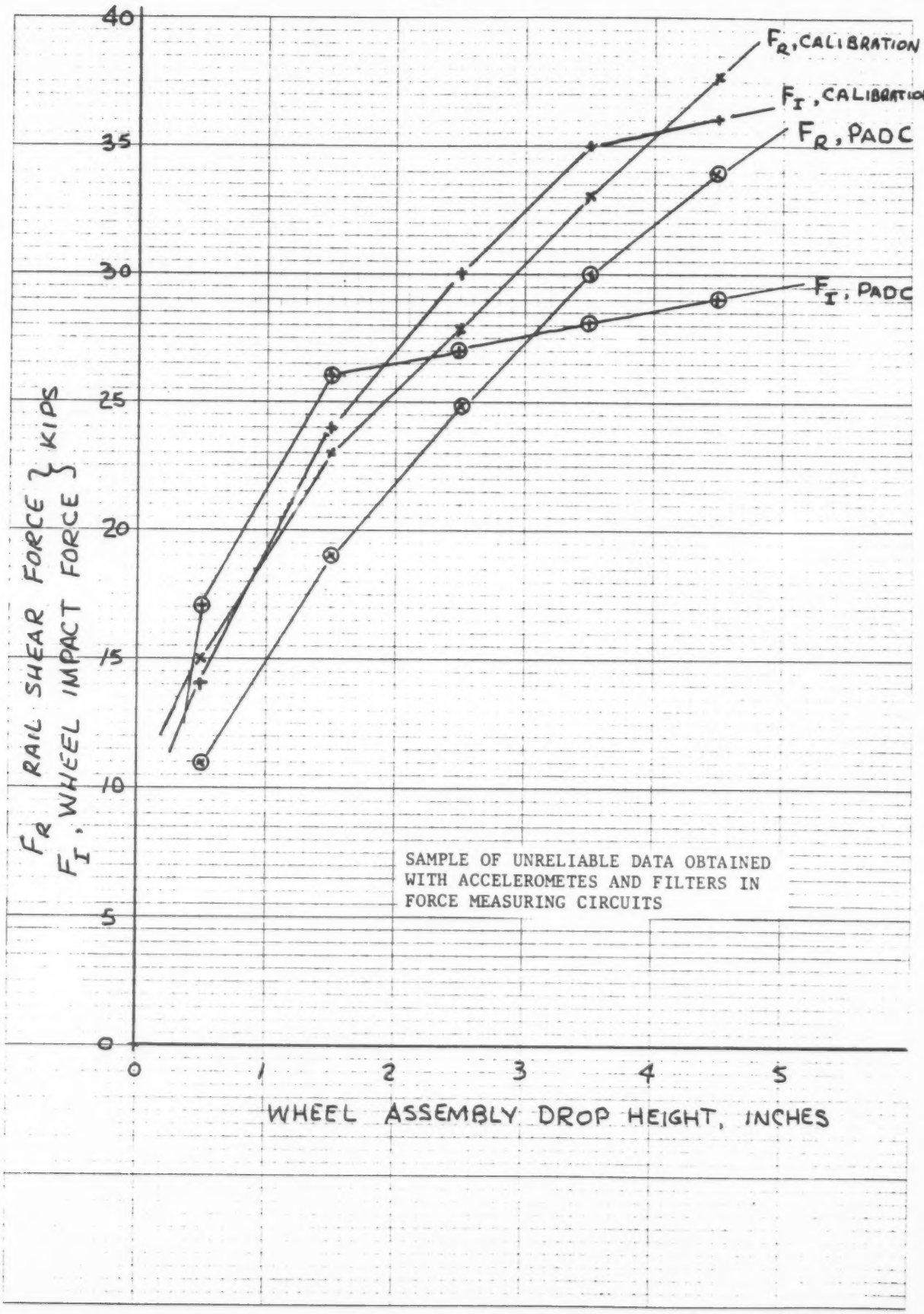


EXHIBIT NO. 22

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10 X 10 TO THE INCH
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A three-tie stub track was set up on a 24 inch thick concrete slab. Douglas Fir plywood 3/4" thick and a soft sponge rubber mat 1/2" thick was placed under the three ties. Unfortunately the test data accumulated was inaccurate as the two-wire receiver equipment had a cut off frequency of only 500 Hz. For instance, at a 3 inch drop height, impact forces of about 26 kips were being recorded whereas in subsequent tests about 60 kips were recorded at the same drop height.

Finally, Honeywell Accudata signal conditioning modules and amplifiers were used to replace the two-wire transmitter data acquisition system, and the data generated was included in this report. The amplifier filter settings were placed at wide band. This setting permitted capture of the full amplitude of the signals and also allowed system noise to be included in the signal. This may help to explain the scatter of data points in the plotted graphs included in this report.

The final change made was the replacement of the plywood-sponge rubber support under the ties with rubber strips (as shown in Exhibit No. 1 of the report) to dampen the vertical reaction of the two outer ties.

Notwithstanding all the measurement difficulties encountered during this project, it is felt that useful information was ultimately obtained.